Exploring the Concept of Resilience in Spatial Planning on the Tsengwen River

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July, 2023

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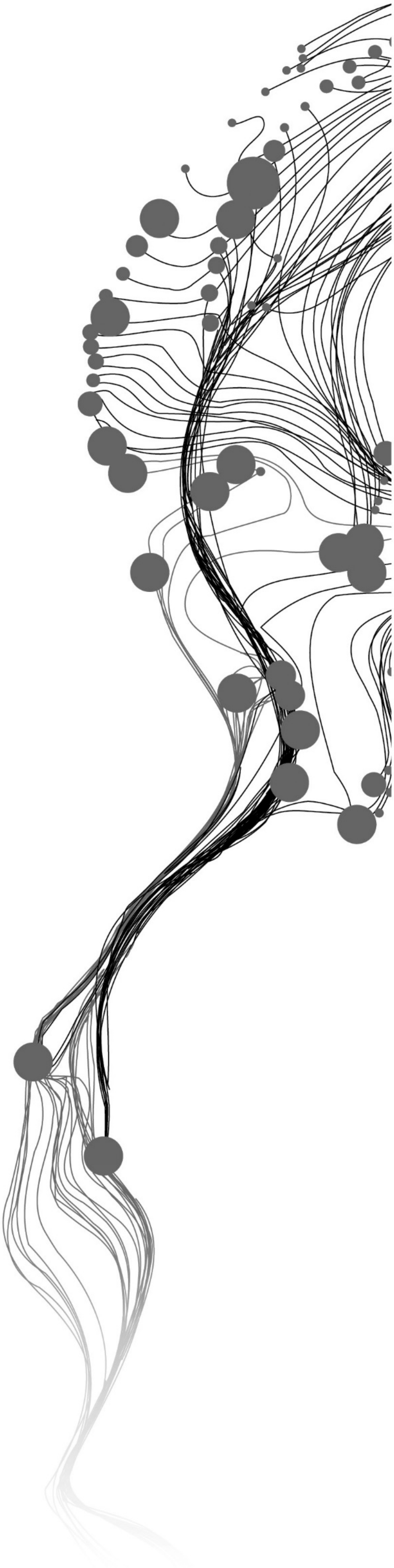

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Enschede, The Netherlands, July, 2023

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: Spatial Engineering / Applied Earth Sciences

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DISCLAIMER

ABSTRACT

The causes and consequences of floods are embedded in complex sociopolitical contexts with numerous stakeholders of various interests and views that impact how problems are formed or perceived. Thus, the challenge of transferring the Dutch Room for the River (RftR) to other jurisdictions is not just about implementing technology, it requires a fundamental shift in the governance and culture. Through a technical analysis of flood modelling simulation and social assessment of applying flood resilience framework and contextual water governance theory, this study assesses how the stakeholders perceive the RftR approach and what is the feasibility of implementing the RftR intervention in Tsengwen River in Taiwan.

The flood modelling is based on rainfall during Typhoon Morakot in 2009, which caused severe damage in southern Taiwan. The simulation shows an excellent performance (NSE = 0.938), and the flood characteristic analysis indicates that the Tsengwen Reservoir plays a crucial role in flood regulation in the Tsengwen River basin. In addition, the proposed interventions, including the RftR approach, optimised dam operation, and detention ponds, are simulated to evaluate the effectiveness of mitigating the flood hazards in the Danei District.

Through applying the flood resilience framework, this study reveals that the current flood risk management strategies are biased towards building the resistance capacity to floods. This tendency might erode the flood resilience in the system. A contextual water governance theory is implemented to assess the complicated interaction among the actors, and how the cultural context, regulations, and previous projects shaped the Tsengwen River basin. These social assessments explicate how flood resilience and water governance framework could complement each other to provide an intact view of complex sociopolitical contexts.

In conclusion, this study explores the possibility of applying the Dutch RftR approach to the water governance system in Taiwan. Gaining a better understanding of the viability of implementing the RftR approach in the Tsengwen River basin could help stakeholders in water governance anticipate and address potential challenges and conflicts that may arise when implementing RftR within unique political and geographical contexts.

Keywords: OpenLISEM, Flood hazards, Room for the River, Flood resilience, Contextual Interaction Theroy, Water governance, Typhoon Morakot, Tsengwen River.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisors, Prof. Dr. V.G. Jetten (Victor) and Dr. C.L. de Boer (Cheryl), for their invaluable guidance, support, and mentorship throughout the entire journey of the thesis. They teach me how to think critically and inspire me to keep the vision of contributing to society. They not only guided me when I was struggling with problems but, more importantly, instilled in me the attitude and principles of conducting scientific research. This attitude is a lifelong gift that will continue to shape my academic and professional pursuits. Also, I would like to thank my mentor, Dr. L. Lombardo (Luigi), for his guidance and support in the first year, particularly in helping me develop my personal development portfolio and refining my study interests.

This journey would not have been as enjoyable, productive, and fulfilling without the presence of these remarkable individuals. Therefore, I would like to thank my study room fellows in Spatial Engineering: Arunima, Aulia, Jafethk, and Santiago, as well as my friends Zannat, Carolina, and others. Your companionship, insightful discussions, and shared experiences have been precious throughout this journey. The exchange of ideas, support during challenging times, and collaborative efforts have significantly contributed to the development of my research. While the study may be concluding, our friendship will keep going.

I am deeply grateful to my parents, brother, and aunt for their unwavering support and encouragement That kind of unconditional love from the family permits me to fly, fly high, and see the world. Their belief in me and their understanding of the importance of my studies allowed me to fully concentrate on my academic pursuits.

Although it is impossible to acknowledge everyone who has played a role in shaping this thesis, I extend my gratitude to each and every individual who has supported me in various capacities throughout this academic journey in ITC. Your contributions and words of encouragement have been instrumental, and I am truly thankful for your presence in my life.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Floods are one of the main weather-related natural hazards that consistently cause human fatality and damage the economy, worth tens of billions of US dollars worldwide (Kundzewicz, Szwed, et al., 2019). It is estimated that the number of people settling in the 100-year return period flood area will increase from 580 million in 2010 to 758 million in 2030 due to population growth and climate change (Tellman et al., 2021). Because of the pressure from the growing population, human activities such as urbanization, deforestation, expansion of agricultural land, and wetlands reclamation have been progressing, which reduce the capacity of the river basin to store water, increasing the runoff coefficient, and exacerbating flood hazards and risk (Kundzewicz, Su, et al., 2019). Moreover, global warming leads to heavier precipitation, creating the possibility of increasing the exposure of humans to flood hazards substantially (Arnell & Gosling, 2016; Swain et al., 2020).

Hydraulic engineering was designed and placed into rivers to control or defend against floods to create more available and safe riverbank land, which provides the accessibility of drinking water, productive land, safeguard barriers, and corridors for navigation (Alfieri et al., 2017). The measure of flood prevention provides considerable advantages such as human safety and food production in the short-term (Warner et al., 2018). However, the conventional flood prevention infrastructure (also called “grey” or “hard” infrastructure) interferes with the environment. The construction of grey infrastructures put significant threats to the sustainability and coherence of the ecosystem resulting from the fragmentation and modification of the landscape, and loss of habitat (Li et al., 2017). The grey infrastructure flood protection strategies, such as artificial levees and dams, are not enough to save people’s lives and property from megaflood events, especially under the climate change impacts (Nakamura, 2022). In addition, the well-known "levee effect," which refers to increased use of floodplain after levee construction or improvement, frequently causes more problems, especially when levees break or are affected by significant flood occurrences (Auerswald et al., 2019). The function of the infrastructure system needs to be designed without relying on the current situation but to have the ability to adapt to an uncertain future by minimizing the severity and duration of breakdown under extreme circumstances (Dong et al., 2017).

Concerning the negative influence of traditional hydraulic infrastructure on society and the environment, several research has been conducted to strike a balance between the values of ecosystem services. To develop better flood risk management strategies, relevant concepts such as the resilience (Fekete et al., 2020; Hartmann & Jüpner, 2020), Nature-based Solutions (NbS) (Hartmann & Slavíková, 2019; Raška et al., 2022), Green and Blue Infrastructure (Green et al., 2021; Thorne et al., 2018), and sustainability (Carter et al., 2009; Shah et al., 2018) have been discussed. The paradigm shift from flood protection to flood risk management is related to the concept of resilience (Hartmann & Jüpner, 2020). The resilience concept, as opposed to resistance, illustrates an innovative approach to flood risk management and it expands its goal to include the capacity to "recover" from a flood event and "adapt" or "transform" the current approach (Zevenbergen et al., 2020) The notion of resilience follows the trend of emphasizing comprehensive solutions to environmental problems (Disse et al., 2020). Furthermore, the shift toward flood resilience has occurred as a result of the uncertainty associated with climate change in order to deal with unforeseen climatic perturbations that have an impact on extreme flows (McClymont et al., 2020). The Room for the River (RftR) programme in the Netherlands is one of the most representable programme for including resilience in the flood risk management context.

Nevertheless, the achievement of the RftR programme is not easy to reproduce in other countries because the flood characteristic and society context, such as culture, government regime, economy, etc., are unique everywhere. As the controlling factors of risks vary temporally and geographically, knowledge of their physical and spatiotemporal characteristics is crucial for forecasting future flood risks and developing efficient flood mitigation strategies (Tanoue et al., 2016). Although the RftR and resilience have already been discussed in the past decade, there is little research on assessing the effectiveness of RftR as a flood mitigation intervention for enhancing resilience in Taiwan. In addition, the paradigm shift must involve the actors in the water governance field. In order to have an overall picture of the water governance system operating in Taiwan, semi-structured interviews were conducted to understand the current water governance regime. This study aims to evaluate the potential of the RftR approach as a flood hazard mitigation measure to enhance flood resilience in the Tsengwen River basin. One particular event is used for flood hazard simulation, typhoon Morakot in 2009, which broke the past 50 years' rainfall intensity records (Xu et al., 2011). Several rainfall stations recorded the rainfall intensity over 200 years return periods with accumulated precipitation of 2,884 mm in the Ali Mountain station in five days (Lin et al., 2011). In the Tsengwen River basin, with the regulation of dam operation, the downstream discharge was curbed down to around 100 years. The floods were widespread in several districts, causing property damage and losses of life.

2. RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

2.1. Main Research Objective

This study aims to assess the potential of implementing the Room for the River approach to enhance resilience in the Tsengwen River basin of Taiwan.

2.2. Sub-Research Objectives and Questions

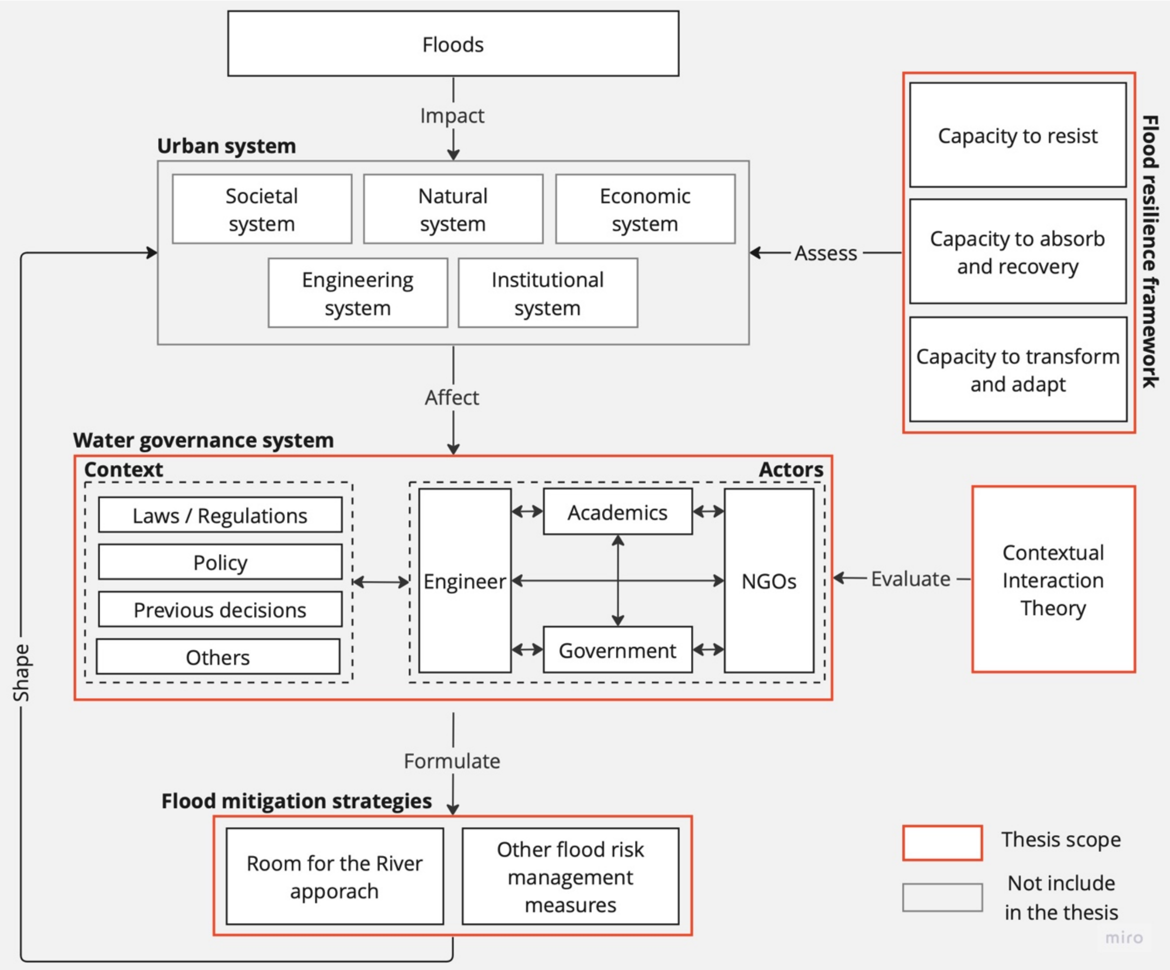
The main objective leads to the following sub-objectives and corresponding research questions:

1. To identify relevant frameworks for assessing flood resilience and the water governance system in the Tsengwen River basin.
    a. How to apply the flood resilience framework which is derived from the literature for assessing flood risk management in the Tsengwen River?
    b. What frameworks can be used to understand the water governance context, and how can this be applied in evaluating flood risk management in the Tsengwen River?
    c. To what extent the RftR approaches could be implemented based on the current governance system for enhancing flood resilience in the Tsengwen River basin?
2. To understand the stakeholder’s perspective on floods and their perspectives on different RftR intervention designs.
    a. What are the interactions among different stakeholders in water management and their perspectives toward flooding?
    b. What are the preferred RtfR designs interventions from stakeholders' perceptions?
3. To develop the flood model openLISEM for the Typhoon Morakot and simulate the flood hazard in the Danei District under different RftR scenarios.
    a. What is the role of the dam water release in the floods of 2009?
    b. Which RftR measures for flood hazard mitigation are possible under these circumstances in the Tsengwen River basin?
    c. What are the spatial extent and height of floods in different designed intervention scenarios in the Tsengwen River basin?

3. CONCEPTUAL FRAMEWORK AND RELATED WORK

3.1. Conceptual Framework

The conceptual framework (figure 3.1) illustrates the relationship between different concepts and theories that are related to this study. Floods are a disturbance to the urban system and have an impact on its functions. The water governance system is responsible for formulating flood mitigation strategies in response to the impact of floods. The decision-making process in the water governance system involves the interactions between the relevant actors and is restricted under the current circumstance, such as regulations, policy, or previous decisions. Contextual Interaction Theory (de Boer, 2012) is used for evaluating this complicated process. The flood mitigation strategies are implemented to shape the urban system to have a higher ability to mitigate the impact of floods. The RftR approach is the main flood mitigation strategy that is going to be explored in this study. These approaches shape the urban systems and create a chance to improve the flood resilience of the system. The relevant concepts will be reviewed in sections 3.2 to 3.5.



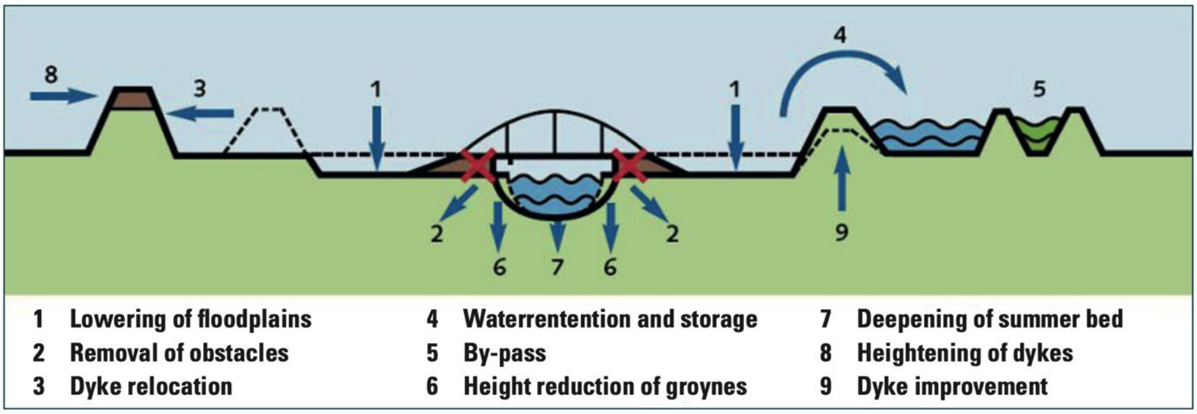
Source: Author. Adapted from de Boer (2012) and Hegger (2016)

Figure 3.1 Conceptual Framework

3.2. Room for the River Programme

The Room for the River programme exemplifies how the flood management paradigm shifts. It demonstrates the attention of flood risk management measures moving away from flood control infrastructure to floodplain restoration (Liao, 2014). The strategy focuses more on nonstructural mitigation than on expensive infrastructure for regulating rivers (Bogdan et al., 2022). The programme incorporates NbS into large-scale planning (OECD, 2020) and ensures residential areas' resilience (Kachi, 2016). The new paradigm offered greater flexibility and resilience against extreme discharges, whereas the old paradigm's water management strategy relied on resistance through dikes (Roth et al., 2021). The RftR illustrates how to implement NbS into practice to enhance resilience in the living area. However, making space for the river means it might require spaces which are valuable for other purposes, such as agriculture or recreation. For this reason, finding the common interest between stakeholders is a challenge in the RftR approach.

The two objectives of the RftR are improving the safety of the riverine area from floods and enhancing its spatial quality (Rijke et al., 2012). Spatial quality is a concept that highlights the overall effect of spatial planning on the living environment and is often linked to livability, preserving open space, and ecological benefits (Yu et al., 2020). Alphen (2020) recognized spatial quality as the balance between hydrological efficiency, ecological resilience, cultural significance, and aesthetics. By using natural processes and more sustainable land use planning to create space for water to spread during high flows, the programme seeks to incorporate flexibility and/or robustness into the primary flood protection system (C. Zevenbergen, van Herk, et al., 2013). The nine measures of RftR are demonstrated in figure 3.2.



Source: Zevenbergen, Rijke, et al. (2013)

Figure 3.2 Room from the River Measures

The RftR approach is not just about technological innovations; it also calls for governance improvements and fundamental shifts in how people view and interact with rivers (Bogdan et al., 2022). It posed a challenge to interact with the residents impacted by river interventions since the approach allowed water to flow rather than being contained and cut off from the human habitation (Roth et al., 2021). In the RftR programme, governance involves not only cooperation across various government levels and disciplines but also a participatory decision-making process with early community engagement (Rijke et al., 2012; C Zevenbergen et al., 2015).

The RftR will be the core concept for this study for designing interventions to enhance the system's resilience. Making room for the river put the designs' focus horizontally but not just strengthening the levees vertically. This thought is lacking in Taiwan hydraulic engineering designs because of limitations in the administration system of water management. For instance, in national basins, the Water Resource Agency only has the administration right with the current levee area, so considering interventions outside the levees is out of their administration scope. However, shifting the attention horizontally brings opportunities for cross-discipline cooperation in the government system. In addition, involving stakeholders in the decision-making process is also absent in the river management system in Taiwan. The RftR programme provides a practical example of how to integrate those successful elements in water management, which is why this study will use it as the main approach when developing interventions.

3.3. Resilience in Flood Risk Management and Governance

The notion of resilience has become popular with water management and flood risk management academics in the past decade (Fekete et al., 2020; Morrison et al., 2018; Rodina, 2019). The terms "flood risk governance" (FRG) and "flood resilience" have emerged as a supplement to strategies emphasizing risk assessments and technical management alternatives (Matczak & Hegger, 2021). The typical strategy for managing flood risk management (FRM) in industrialized countries has frequently been to use resistance-based strategies, such as trying to limit flood hazards with infrastructure and controlling behaviour with laws and regulations; however, it does not deal with uncertainty well (Morrison et al., 2018). The field of flood risk management has experienced a conceptual transformation, which is also termed a paradigm shift, from structural flood defence to nonstructural management measures or from flood defence to “living with” floods (Fekete et al., 2020). This paradigm shift in flood risk management can also rephrase as resistance (defending against floods) towards resilience (adapting to floods) (Hartmann & Driessen, 2017). The notion of resilience has been proposed as the ideal and desired outcome of flood risk management in the scientific literature (Driessen et al., 2018).

Holling introduced the notion of resilience from the ecology aspect in 1973, and its popularity grew in multiple disciplines, such as engineering, disaster management, socio-ecological systems, psychology, and economics in recent years (Laurien et al., 2020; McClymont et al., 2020). The initial definition of resilience by Holling (1973) is “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.” The broadest interpretation of resilience’s application to flood management aims to lessen the negative impacts of severe events, which may otherwise be devastating for communities and perhaps lead to disaster (Disse et al., 2020). Liao (2012) considered flood resilience has two essential elements, which are the capacity to tolerate floods and the ability to reorganize quickly. Hegger (2016) operationalized the characteristic of resilience into three capacities, which are resistance, absorption & recovery, and adaptation & transformation. Although the concept of resilience has been discussed for a long time, it is still difficult to assess resilience. The reason is partly that there isn't a consensus on a definition (yet), which makes the choice of resilience indicators a hotly debated topic; in addition, it is partly also because resilience is about the interaction between individuals (e.g., prior experiences, income level, health status) and the physical environment (e.g., flood protection level, material selection for flood barriers, structures) in the flood domain (Zevenbergen et al., 2020).

There are several research aiming to assess urban flood resilience. Rezende (2019) introduced the Urban Flood Resilience Index, which included flood hazards, social vulnerability, and exposure indicators to quantify urban resilience to floods. Barreiro (2021) applied 1D/2D modelling to the urban drainage system and evaluated the flood hazards and affected services to assess flood resilience. Batica (2013) evaluated flood resilience from the availability of urban functions such as energy, water, transport, etc., and graded the indicators from levels 0 to 5. Tayyab (2021) used a GIS-based model to assess urban flood resilience; the Analytic Hierarchy Process method was used for weighting spatial data, which refers to sensitivity and capacity. From the previous research reviews, it is noticed that the indicators and methods among them are different, and only a few of them take the societal indicators into account. In addition, the studies only assess the static status of resilience but do not analyze the dynamic change of resilience or compare the difference of resilience in different scenarios. Chen (2019) used a time-varying method to demonstrate the change in flood resilience over time. Miguez (2017) compared the present scenario and future scenario. Bertilsson (2019) took annual savings as an indicator to represent the recovery capacity. Although some have tried to address those issues, the research methods and scales are different. Cutter (2016) pointed out that most of the research on resilience assessment is focused on measuring assets, and there is only little acknowledging of the intricacy of the community or system. Some critiqued that using the system as the unit of analysis is too decontextualized, technical, and apolitical (Dewulf et al., 2019). Rodina (2019) found that although resilience is frequently used as a specific, measurable system attribute in engineering, it is still primarily a conceptual construct in water governance.

Instead of specifying resilience as an abstract characteristic of a formally defined system, it can be seen as being continuously lived and experienced by various actors in various ways (Dewulf et al., 2019). Flood risk governance, which is understood as steering public and private actors in societal and political decision-making, plays a crucial role in the degree of flood resilience to society (Matczak & Hegger, 2021). Research in flood risk governance has the ability to offer fundamental insights into the discussion of how to increase societal resilience to floods (Driessen et al., 2016). Although there is emerging literature related to flood risk governance, there is a lack of integration in the studies supporting the governance of FRM for resilience, and solutions to address this lack of integration are inadequately researched (Morrison et al., 2018). The research from Rodina (2019) summarized that there are still large empirical and conceptual gaps, notably in integrating the many water governance subsectors and, more crucially, in the institutional and governance aspects of constructing water resilience. Hegger (2016) also stated that although it makes instinctive sense to draw a connection between the availability of a wide variety of flood risk management strategies and an urban system's level of flood resilience, the empirical data supporting this association is still tentative.

Flood resilience is a concept that describes the desired outcome of an internal property of a system or an objective of flood risk management. This study assumes that enhancing the resilience of the system as a goal of intervention designs can assemble the knowledge from different disciplines and various groups of people to come up with a flood mitigation strategy that covers aspects such as hydraulic engineering, landscape planning, ecology, etc. Although flood resilience does not have a consensus definition yet, some similarities can be found in scientific research. The selection of flood resilience indicators is based on the common points from the literature, and the indicators will be used to assess how the system responds to floods. The flood resilience framework (table 3.1) from Hegger (2016), which operationalised flood resilience into capacities (the capacity to resist, the capacity to absorb and recover, and the capacity to adapt and transform) based on the literature review, was used for flood risk management assessment in this study.

Table 3.1 Flood Resilience Framework

Form of capacity	Definition	Indicators
Capacity to resist	"The ability not to be adversely affected by floods, by increasing the threshold above which floods can cause harm"	Adequately timed implementation of flood-resistance measures: • Structural measures • Upstream retention
Capacity to absorb and recover	"The ability of a flood-affected system to remain functioning, respond to a flood, and recover (without shifting to a different system state)"	Adequately timed implementation for response to and/or recover from floods: • Flood mitigation measures • Insurance systems • Warning and forecasting system • Presence of flood awareness

Capacity to transform and adapt	“The ability of a system to adjust to external drivers affecting the exposure of people and economic assets to floods (including climate change, climate variability, and changes in extremes, demographic changes, and changes in urbanization patterns) to moderate potential damages, to take advantage of opportunities, to make deliberate small-scale changes, or to cope with the consequences.”	• Existence of institutionalized learning mechanisms • Evidence that actors connected to institutions and local communities are capable of embracing novel ideas and viewpoints.

Source: Hegger (2016)

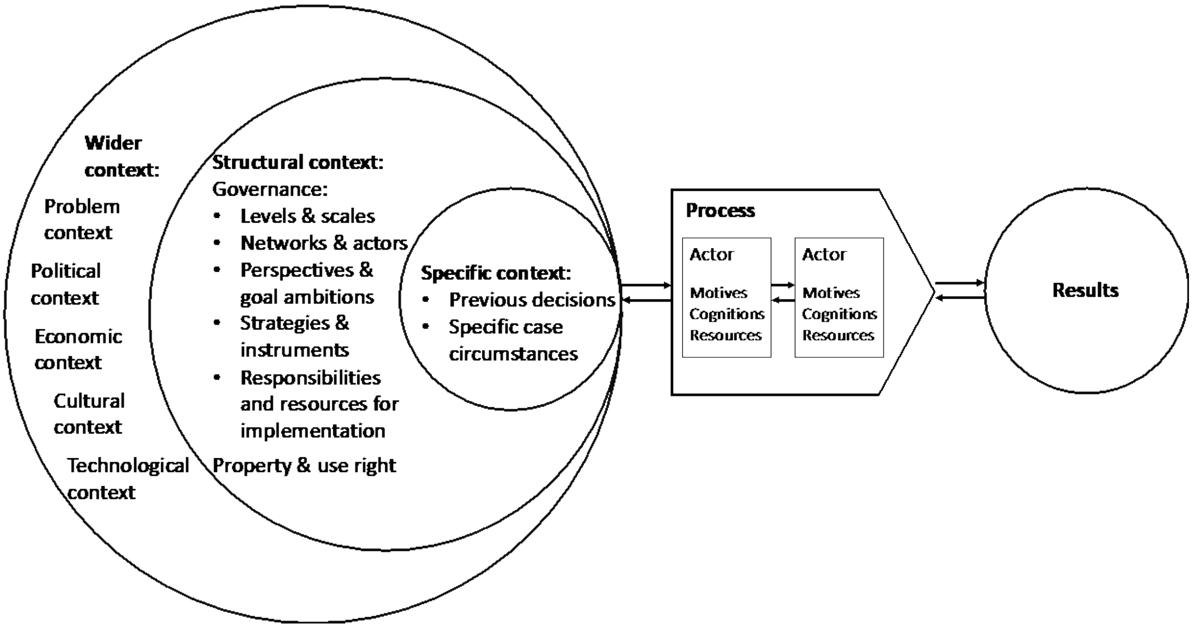
3.4. Contextual Interaction Theory

With the recognition of the crucial rule of actors’ interaction in the water governance system and the lack of the coinciding flood risk governance definition, it is necessary to adopt an existing water governance framework to evaluate the governance system in the flood risk management context.

The resilience-thinking in water-related governance has grown its popularity in the past decade. Several research used the resilience concept as a lens to evaluate the outcome of governance; however, current resilience studies to the water-related risk still remain some challenges and unanswered questions. Fallon (2022) summarized the challenges into three points. First, less research has been done on the resilience theory's potential to help us understand the characteristics and the processes of governance arrangements. Second, the core of how governance operates, such as the political, power, and equity challenges, are missing in the resilience theory. Third, resilience thinking in governance places more emphasis on a system's capacity to "bounce back" than on its potential to "bounce forward."

In order to have a better understanding of governance characteristics and processes, it is valuable to use a governance assessment framework to complement the insufficient part of the resilience concept. The governance perspective evaluates the capacity of the governing actors to cooperate, tests the presence and effectiveness of policy strategies and instruments, provides insight into mechanisms through which strategies, actors, levels, and sectors can be connected, and it may lead to changes in societal discussions and institutional settings (Hegger, Driessen, & Bakker, 2016). In this study, the Contextual Interaction Theory (CIT) (de Boer, 2012) was selected to be the water governance assessment framework because it complements the challenges of resilience in governance that were pointed out by Fallon (2022). For instance, the CIT framework helps to understand the characteristics of governance regimes and the interaction among the actors in decision-making, which are not well addressed in the resilience framework. It is expected that the process of water governance in Taiwan can be explained by using the CIT framework to analyze the interview feedback from core stakeholders on the proposed RftR intervention.

The CIT framework’s definition of implementation is that it consists of “the process(es) that concern the application of relevant policy instruments, including the realization of projects to achieve physical changes (buildings, infrastructure, landscaping) (de Boer, 2012).” The basic assumption of the CIT is “there is a dynamic interaction between the key actor-characteristics that drive social-interaction processes and in turn are reshaped by the process (Bressers, 2007)”. The structure of the CIT framework is shown in figure 3.3. This framework perceives that the actors’ interaction process can be understood from the stakeholder’s characteristics: motivations, cognitions, and resources. In this CIT framework, motivation refers to the driver of the actor’s action, cognition means the interpretations of reality by the actors, and the resource is about the power and capacity of actors (de Boer, 2012) The three characteristics are not only the being inherent to the actors and affected by the process but also affected by external multi-layered context, which consists of the wider context, structural context, and specific context (de Boer, 2012). For example, the actors can be influenced by circumstances in the specific case such as geographic conditions, and structural contexts such as the policy and use right of resources. On the other hand, the interactions among the actors also can affect the specific context and structural context.



Sources: de Boer (2012)

Figure 3.3 Multi-layered Contexts of the CIT Model

In this study, the proposed RftR intervention in the Tsengwen River is used to explore how the relevant stakeholder reacts to this proposal. The CIT framework is applied as an analysis tool to provide a better understanding of the actors' interaction involving their motivation, cognition, resources, and the dynamic process in water governance.

4. RESEARCH METHODS AND DESIGN

4.1. Study Area

The Tsengwen River basin (figure 4.1) is in south-eastern Taiwan with 1,177 km^2 of catchment area with about 139 km mainstream length. The upstream of this catchment is part of Ali Mountain, with a high elevation (2,600 m), and over half of the area is on a steep slope (<40%). This catchment has three reservoirs; the Tsengwen Reservoir is the biggest one, with an initial design capacity of about 700 billion cubic meters, and the spillway capacity can reach 9,470 m^3/s. The other two reservoirs, named Nunhua and Wushantou are free-overflow dams. The wet season is from May to September. The mountains area has about 3,000 to 4,000 mm of yearly precipitation, and the coastal area has about 1,000 to 1,600 mm. The river accommodates water from upstream runoff, reservoir discharge, tributaries, etc., and the landscape of the area determines how fast the water flows. The catchment administration system in the Tsengwen River basin is demonstrated in figure 4.2.

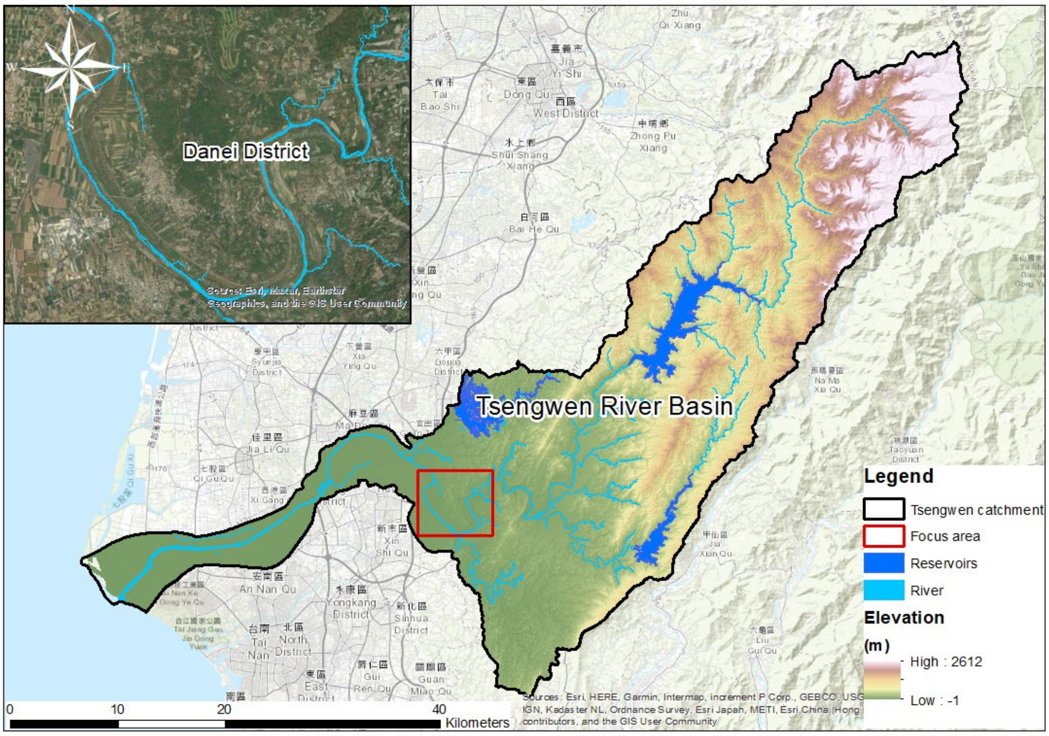


Figure 4.1 Tsengwen River Basin and Focus Area

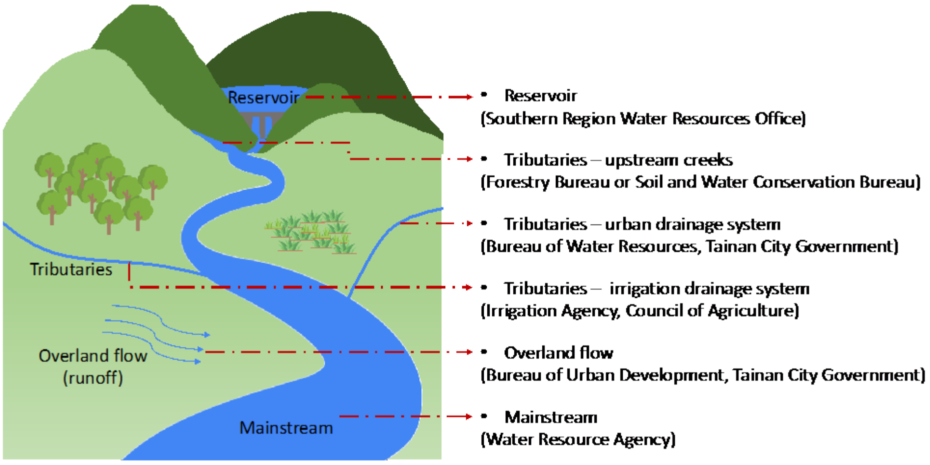
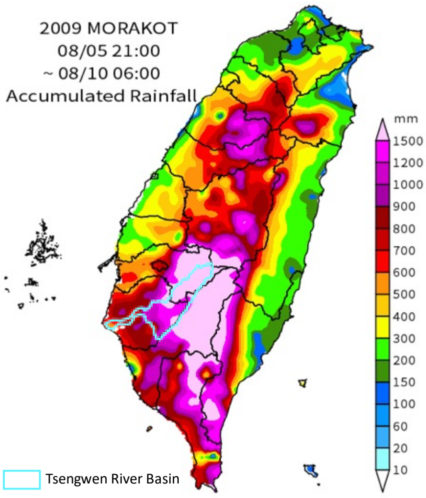


Figure 4.2 Tsengwen River System

Typhoons with tremendous rainfall and devastating wind hit Taiwan frequently and trigger floods, landslides, and mudflow. In 2009, Typhoon Morakot carried 2,884 mm participation recorded at Ali Mountain Station (Lin et al., 2011). It was indicated that the rainfall return period in this event was over 200-year (Chang et al., 2013). About 9,590 meters of levees in the main river were damaged, 700 people died or went missing, and around 550 million US dollars were lost in agriculture due to Typhoon Morakot (translated from Water Resource Agency report by Shieh (2010)). The accumulated rainfall from Typhoon Morakot in Taiwan is displed in figure 4.3. During the event, Danei District was one of the most damaged areas in the Typhoon Morakot event, with a flood height of 1-2 meters. Figure 4.4, which is from the after-event investigation report made by the Sixth River Management Office, Water Resource Agency, demonstrates the flood inundated area caused by the Tyhoon Morakot. The leading causes of floods in the basin include overflows exceeding levees level and unexpected discharges from reservoirs (Shieh et al., 2010). Danei District, located in the middle stream of the Tsengwen River, is the focus area of this study. This selection is based on two reasons: (1) it was the most damaged village in the Typhoon Morakot event, with flood height reaching almost 2 meters; (2) the surrounding area of the district still has some flat space for the RftR design.



Source: National Science and Technology Center for Disaster Reduction[1]

Figure 4.3 Accumulated Rainfall from Typhoon Morakot

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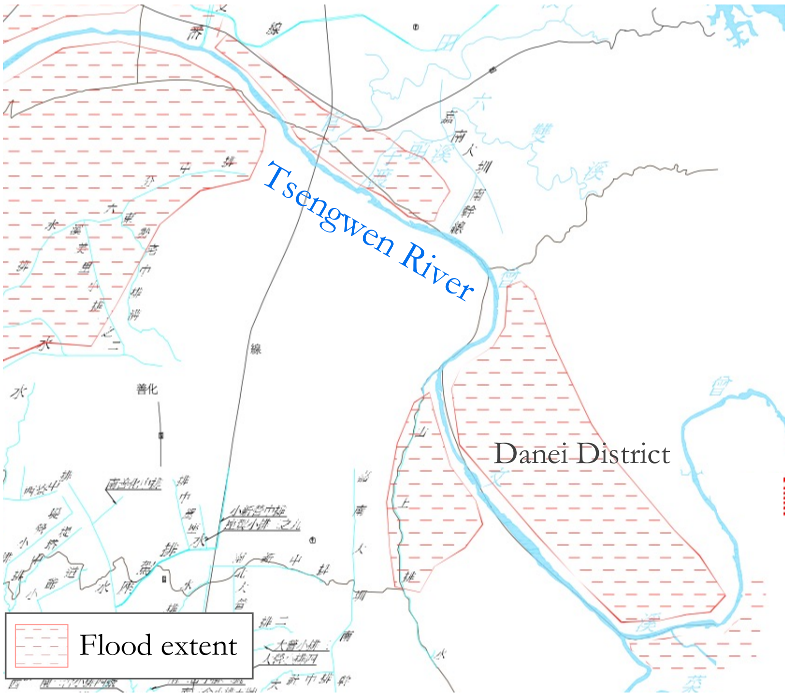
[1] https://den.ncdr.nat.gov.tw/umbraco/surface/CustomTyphoon/TyphoonRainImage?nodeId=2505



Source: The Sixth River Management Office. Adapt to the focus area by Author[2]

Figure 4.4 Flood Extent of Typhoon Morakot in the Focus Area

4.2. Workflow

The workflow (figure 4.5) is developed to illustrate how the research was conducted and how the methods correspond to the research objectives in Chapter 2. The details of flood modelling and semi-structured interview will be explained in sections 4.3 and 4.4. This section will illustrate how the study was conducted. The process of this study can be divided into three parts:

Part 1: Identify frameworks and apply them for assessing flood risk management and governance

This study selected a resilience framework with indicators that can interpret flood resilience based on the literature reviews, which was used for assessing how the water governance system responds to floods. In addition, the Contextual Interaction Theory was selected as a governance assessment framework to help to evaluate the dynamic process between actors in water governance. These frameworks were used for developing the questions of the semi-structured interview and applied to assess the flood risk management and governance in the Tsengwen River basin. The outcome of this part corresponds to the objective 1.

Part 2: Semi-structured interviews

The semi-structured interviews were conducted with different stakeholders to understand the associated stakeholders' roles and their perceptions of the RftR designs. The questions were formulated based on the selected frameworks in part 1. After discussing the initial RftR scenarios with stakeholders, their preferences and concerns will be comprehended to build the final RftR scenarios. The outcome of this part corresponds to objective 2.

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[2] The Typhoon Morakot post-event report by The Sixth River Management Office, Water Resource Agency in 2009.

Part 3: Recognize the leading causes of the 2009 flood and simulate RftR interventions

The OpenLISEM model was built based on available data and calibrated by the observed discharge records in Typhoon Morakot events. The model simulated the flood hazards of Typhoon Morakot to identify the leading causes of floods. The potential locations of RftR interventions will be identified by upscaling the focus along upstream riverine areas learned from the case study in the Netherlands. Then, some initial intervention designs of RftR scenarios were developed based on the understanding of the characteristics of the focus river segment. The designed intervention scenarios were simulated by OpenLISEM to analyze their effectiveness in mitigating flood hazards. The scenarios were designed based on the stakeholder perception of interventions, the combination of interventions, and the dam operations. These scenarios are compared with the current circumstance. The outcome of this part corresponds to objective 3.

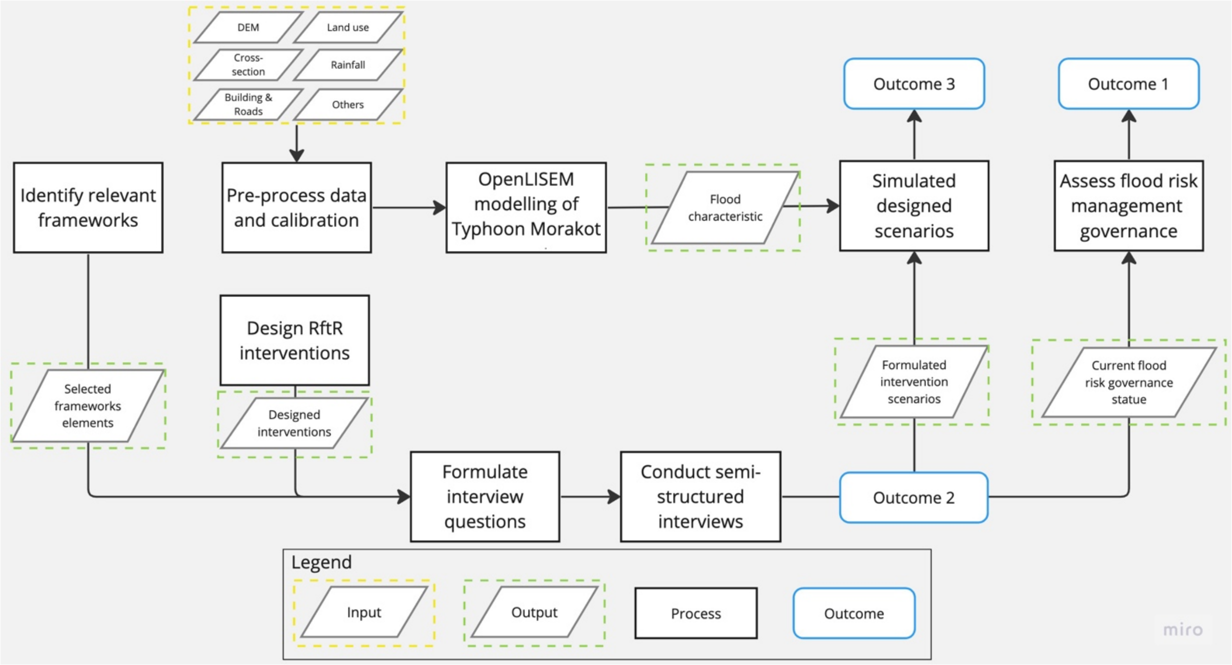

Figure 4.5 Workflow

4.3. Flood Modeling (OpenLISEM)

This study uses the Open Source Limburg Soil Erosion Model (OpenLISEM)[3] software to simulate flood hazards. It is often utilized for simulating runoff, flash floods, and erosion in a single event (Pratomo et al., 2016). Figure 4.6 illustrates how the OpenLISEM simulates hydrological processes, and figure 4.7 displays the required input data for simulation. The model uses spatial data layers that describe the soil hydrology, surface conditions and infrastructure, the terrain and river channels. Where needed, the data is offered as the fraction of a gridcell and combined to a hydrological response of a gridcell. For instance, if the vegetation cover of a gridcell is 50%, half of the gridcell has interception by plants, and the other half has direct rainfall to the soil, which is given to the infiltration process in a combined flux. Other fractions of information per gridcell can be roads and houses, channels, soil compaction etc., (see figure 4.7). The infiltration is done with a 2-layer Green & Ampt model. The topsoil is defined as the root zone, the subsoil is estimated to be a bedrock level. Within the second layer, groundwater flow can develop.

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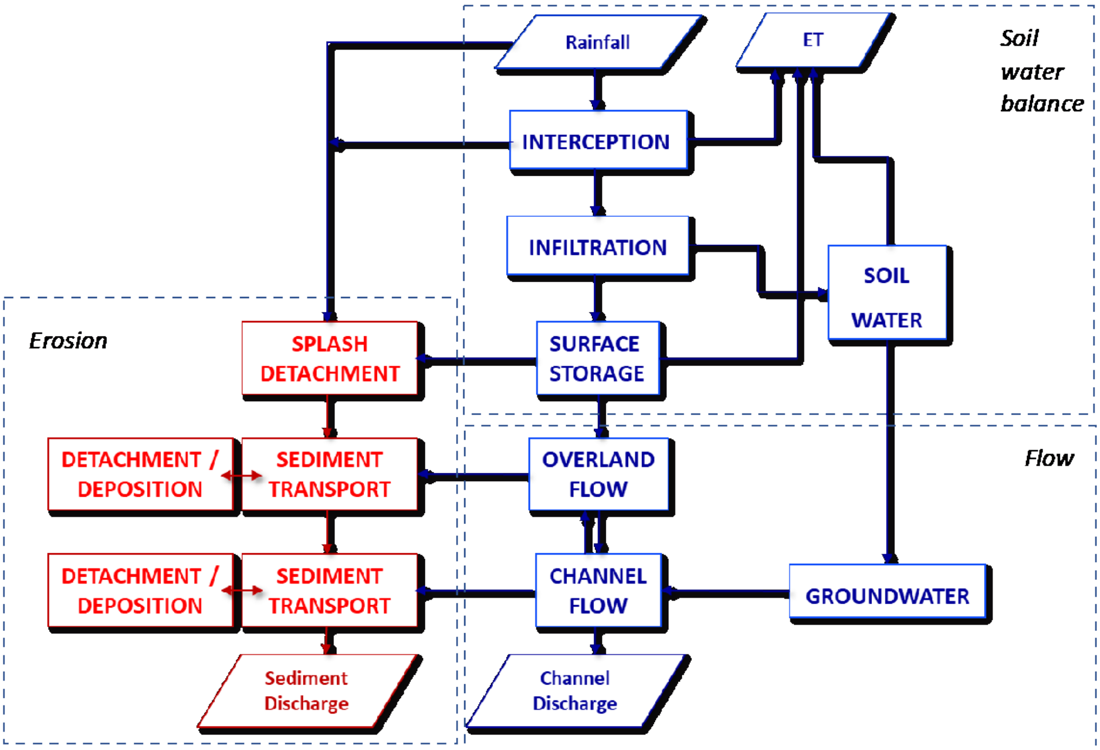
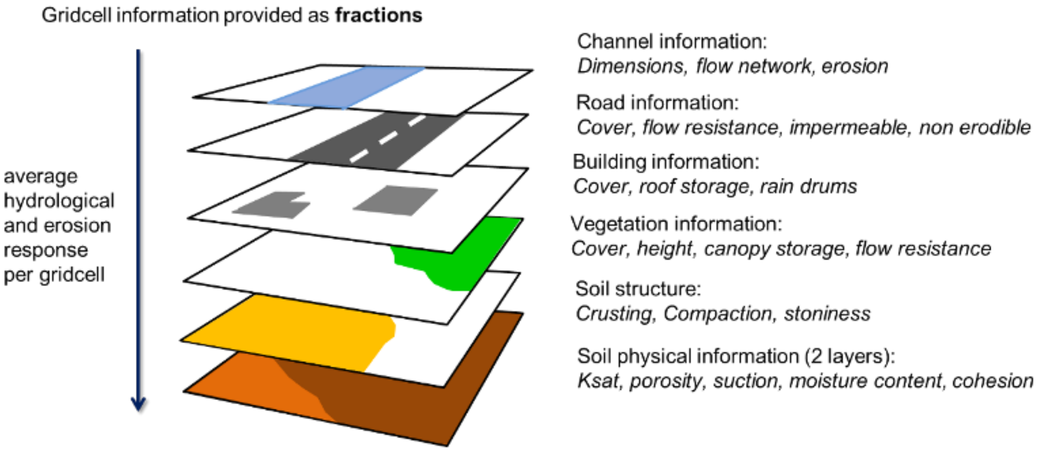
[3] https://github.com/vjetten/openlisem

The hydrological parameters include Saturated Hydraulic Conductivity (mm/h), Porosity (-) and Initial Moisture Content (-). These parameters are obtained through pedotransfer functions (Saxton & Rawls, 2006) from the sand, silt and clay content of the soil layers, the organic matter and the bulk density. These primary soil properties are obtained from the ISRIC opensource database Soilgrids[4], which provides these properties in a 250m resolution worldwide, for six depths (0-5, 5-15, 15-30, 30-60, 60-120, 120-200cm), as demonstrated in previous studies (e.g. Poggio (2021)).



Source: Bout & Jetten (2018a)[5]

Figure 4.6 OpenLISEM Structure



Source: Bout & Jetten (2018a)[6]

Figure 4.7 The Input Data of OpenLISEM

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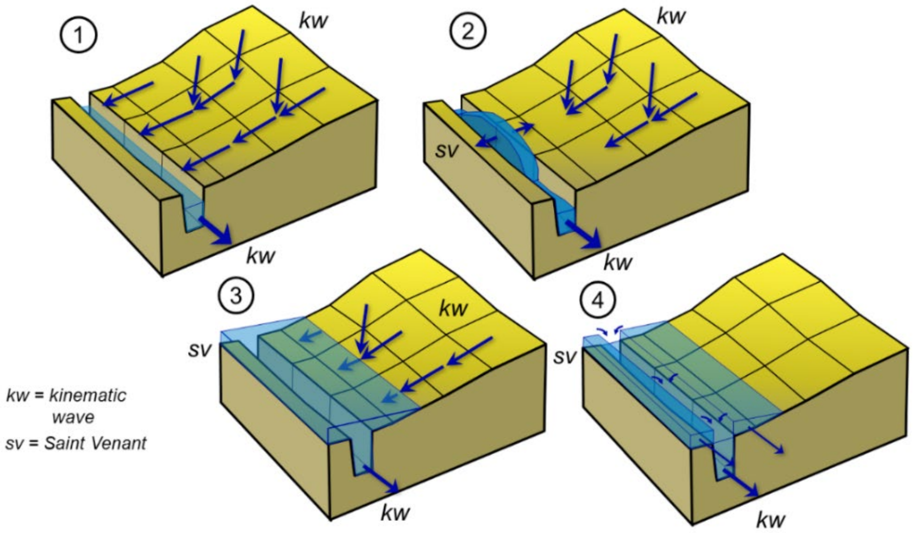
[4] https://Soilgrids.org

[5] OpenLISEM user manual. The figure was modified by the manual author Victor Jetten in 2023.

[6] OpenLISEM user manual. The figure was modified by the manual author Victor Jetten in 2023.

OpenLISEM is fully distributed in space and uses a topography-following grid to deal with both cell-specific processes and the differential equations governing the water flow (Bout et al., 2018). As shown in figure 4.8, the OpenLISEM uses a full dynamic wave for all surface flow (there is no numerical distinction between runoff and floods). After interception and infiltration, all water on the surface flows into the river, which can overflow and mix with the runoff water. The flow in the river channel is a 1-dimensional kinematic wave. The dynamic wave is based on a finite volume semi-explicit solution (Delestre et al., 2017), while the kinematic wave in the river follows a classic implicit solution and iteration (Singh, 2006). Apart from the pressure differences and momentum differences of the flow, the surface flow is determined by the terrain slope and Manning's n for flow resistance. The discharge is determined by the channel dimensions and bed slope, and Manning's n of the channel.



Source: Bout, & Jetten (2018b)

Figure 4.8 Coupling of Overland Flow, Channel Flow and Flooding in OpenLISEM

Floods occur when the amount of water from different sources exceeds the system's capacity. Clarifying the contribution of different water sources that cause floods can help in understanding the composition of floods. The RftR approach is not just considering intervention within the levees; in contrast, it also looks at the area outside the levees. OpenLISEM allows the user to alter the different topography input files as designing interventions. The flood modelling results can provide the flood hazards characteristic such as flood height, flood duration, flood extension, etc. These features of OpenLISEM make it a suitable tool for this study.

4.4. Semi-structured Interview

The semi-structured interview will be conducted by involving the people associated with water governance in order to understand their perspective toward floods and bring local experience and knowledge into intervention designs. In addition, it can also contribute to recognizing the potential conflicts among stakeholders (Guðlaugsson et al., 2020). Conducting semi-structured interviews with key stakeholders is an effective way to collect essential information about intervention design and assessment of flood resilience. Balancing the composition of stakeholders' knowledge and their concerns is essential (Clemens et al., 2014). Edelenbos et al. (2011) categorized the knowledge in the decision-making process into three types: (1) Expert (or scientific) knowledge; (2) Administrative (or bureaucratic) knowledge; (3) Stakeholder (not an expert or administrative) knowledge. Through the semi-structured interview with experts, it is expected that the overview of the problems and the potential tools or solutions can be identified. People who work in the government can provide their perspective on the feasibility based on the regulation or administrative restriction. Since there is a limitation to reaching local citizens from abroad, the residents are not involved in the semi-structured interview in this study.

The selection of the interviewees is based on their responsibility (government), social issues interests (NGOs), and their specialism (researchers and engineers). The diversity of the interviewees could benefit this study by giving a systemic view of the complex water governance system. The lists of interviewees are listed in table 4.1.

Table 4.1 The Interviewee List for Semi-structure Interviews

Interviewees code	**Type of organizations**	**Knowledge type**	**Expertise**
1	National government	Administrative	Climate change adaptation; River management; Water governance
2	Regional government	Administrative	River management; Flood risk management; Water governance
3	Regional government	Administrative	River management; Flood risk management; Water governance; Knowledge of the Tsengwen River basin
4	National NGO/University	Expert (Academic)	Flood resilience; resilience thinking; ecosystem services; nature-based-solutions; sustainable stormwater management
5	National NGO	Expert (NGO)	Water governance; Public participatory
6	National NGO	Expert (NGO)	Spatial analysis; River restoration; Natural resource management
7	Academic research	Expert (Academic)	Climate change adaptation; Water management; Flood risk management, Early warning system
8	Engineering consultant company	Expert (Engineer)	Fluvial morphology; River restoration; Landscape planning; Ecological engineering
9	Engineering consultant company	Expert (Engineer)	Flood risk management, Early warning system; Hydraulic and hydrological analysis
10	Engineering consultant company	Expert (Engineer)	Hydraulic and hydrological analysis; River management

5. DATA PREPARATION FOR MODELLING

5.1. Modelling Domain

The modelling domain (figure 5.1) was generated from the control point that is near the downstream discharge station from the focus area. The upstream boundary is close to the outlet point of the Tsengwen Reservoir's spillway. Since the water that accumulated from the upstream was regulated by Tsengwen Reservior's gate, the spillway's discharge can be used to inject into the channel directly.

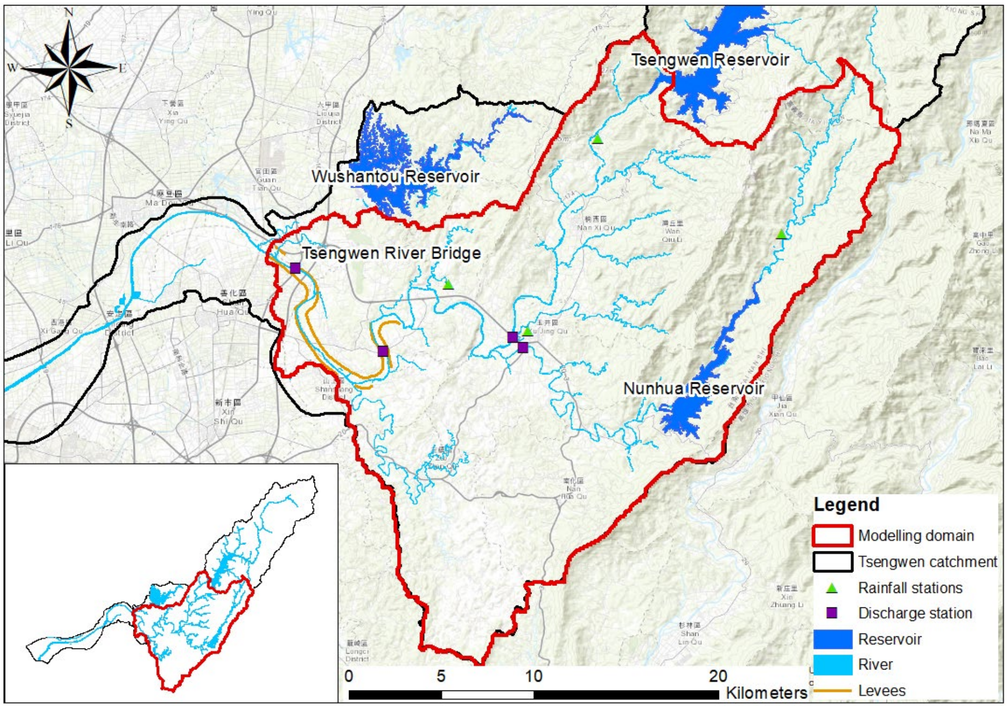


Figure 5.1 Modelling Domain

5.2. Data Pre-processing for Flood Modelling

OpenLISEM requires several input data for simulation, and some of the data requires pre-processing to make the data meet the demand of OpenLISEM. The data pre-processing applied pedotransfer functions from literature; for instance, the soil texture was converted to Ksat, porosity, etc. Table 5.1 lists the data source, and the following sections will illustrate how the input data of the flood simulation was prepared. The important pre-processed input maps, such as Ksat, porosity, Manning's, etc. (shown in Annex 1), can be multiplied with calibration factors for the entire map.

Table 5.1 Source of Data

ID	Input data	Year	File type	Sources
1	DTM	2016	tif	National Land Surveying and Mapping Center
2	Cross section	2012	csv	Water Resource Agency

3	Land use	2016	shp	Construction and Planning Agency
4	Precipitation (mm/hr)	2009. Aug	csv	Central Weather Bureau
5	Soil texture map	-	tif	SoilGrids
6	Road network	-	shp	Open street map
7	Building footprint	2016	shp	Construction and Planning Agency

5.2.1. Digital Terrain Model (DTM)

The DTM is obtained from the National Land Surveying and Mapping Center in Taiwan. The DTM was generated by the Airborne LiDAR technique with a 1-meter resolution. The project was launched in 2010 in response to the damage of Typhoon Morakot and renewed the DTM annually by region. For security concerns, only 20-meter resolution DTM is published as open source. In this study, the 20 m DTM was resampled by the bilinear method into 100 m for the flood simulation. Because the 20 m resolution is too fine for this study, it would require a significant amount of computation time. In addition, the purpose of this study is not for precise intervention design but to explore whether the intervention can mitigate flood hazards in general. Therefore, the DTM and all other layers were resampled to a gird of 100m. This is an arbitrary and practical choice, based on the time available for this research, and the model development process and scenario modelling.

5.2.2. Precipitation

Four rainfall gauge stations fall in the modelling domain. The data was downloaded from the Central Weather Bureau with hourly rainfall records. In this study, the inverse distance interpolation method was used to calculate the rainfall spatial distribution. As distance increase, the weighting of the rainfall decrease. In the modelling domain, the maximum rainfall in 72 hours (August 6th 22:00 to 9th 22:00) during the Typhoon Morakot event reached around 1,380 mm. The maximum daily rainfall was around 830 mm, from August 8th at 11:00 till August 9th at 11:00, with a peak of 72mm/hr average intensity in the modelling domain. The rainfall hydrograph for the whole simulation period is shown in figure 5.2.

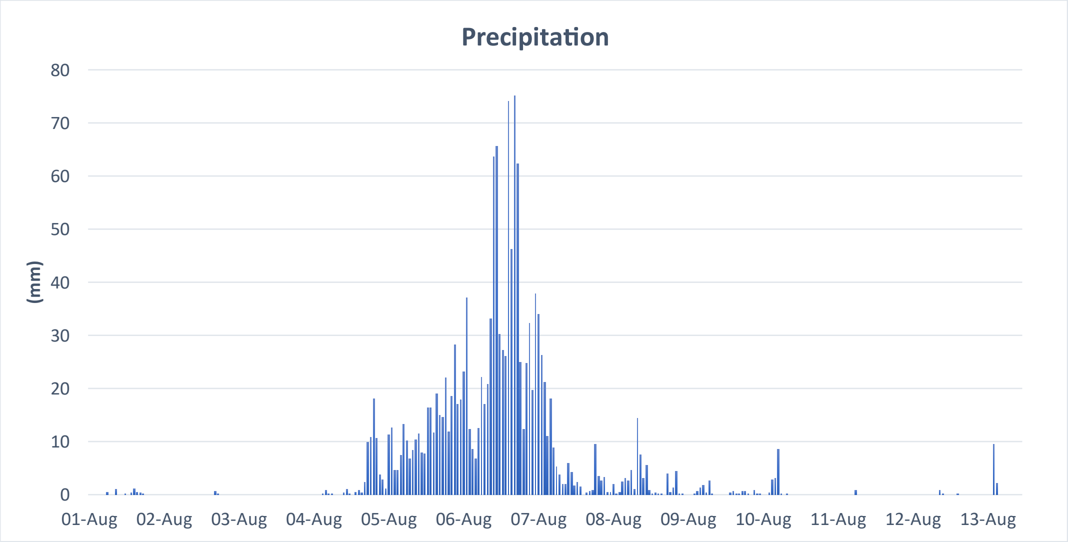


Figure 5.2 Rainfall Hydrograph for the Simulation

5.2.3. Channel and Levees

The survey's cross-section data was used for defining the depth and width of the channel and the height of the levees. The channel network was generated based on the DTM elevation and slope; however, the remote sensing cannot abstract the terrain beneath the water surface. For this reason, OpenLISEM used empirical algorithms that relate the channel width to the river length, as proposed by Allen and Pavelsky (2015). Allen and Pavelsky's (2015) study is based on the rivers in North America, which used mean discharge as the width of a river and found that the relation of width and the accumulated distance in the natural river is a power function. Nevertheless, the Tsengwen River is a highly human-influenced river with dams and levees construction; in addition, the result from North America might not represent the geography of a small island such as Taiwan well. For this reason, this study used the survey cross-section data to calculate the regression formula of distance & width and width & depth. The goal is to ensure that the cross-section in the model possesses a comparable capacity to hold water as it does in the real world.

There are noticeable differences between the DTM and survey cross-section data, especially at the levee and riverbed. Figure 5.3 demonstrates how the reference points in the cross-section data were assigned to determine the width and depth of the channel and the height of the levees. The red line is the elevation from the DTM, the blue is the survey cross-section data, and the yellow dash line is the modified elevation based on the survey cross-section. This comparison displays the inadequacy of direct using DTM for flood modelling. Although higher resolution can reflect more detail of the terrain, it still has the limitation of capturing riverbed elevation beneath the water level.

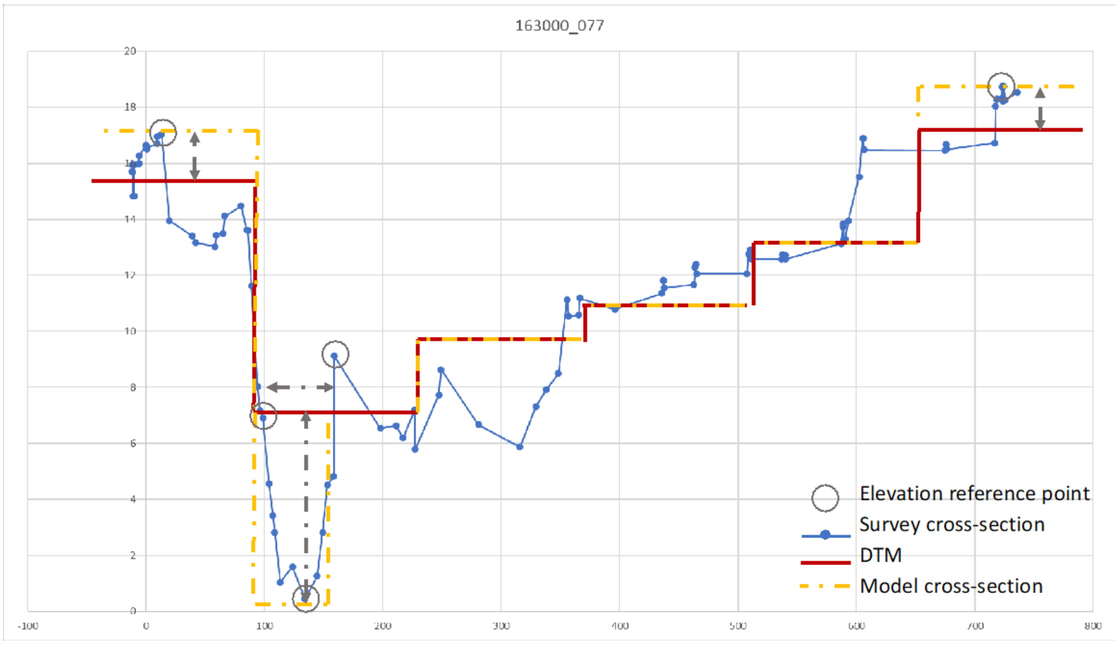


Figure 5.3 Comparison of DTM and Cross-section Data

In this study, two regression formulas were employed in the OpenLISEM for building levees and creating channels. Around one hundred cross-sections were used for regression analysis. In figure 5.4, the power regression of length and width was calculated by the width and accumulated distance from the cross-section data. For the regression of width and depth, the logarithmic regression (figure 5.5) was selected due to its highest R-squared value. The equations for width and depth are as follows:

$$y = 0.1861x^{0.6046}$$ (where y is width and x is length)….. (eq 5.1)

$$y = -2.666 \ln x + 15.76$$ (where y is depth and y is width)….. (eq. 5.2)

Note that the cumulative length towards the outlet depends on the chosen starting point of the river channel. The start point of the simulated river was verified on a high-resolution image in Google Earth, and the distance between each cross-section was calculated.

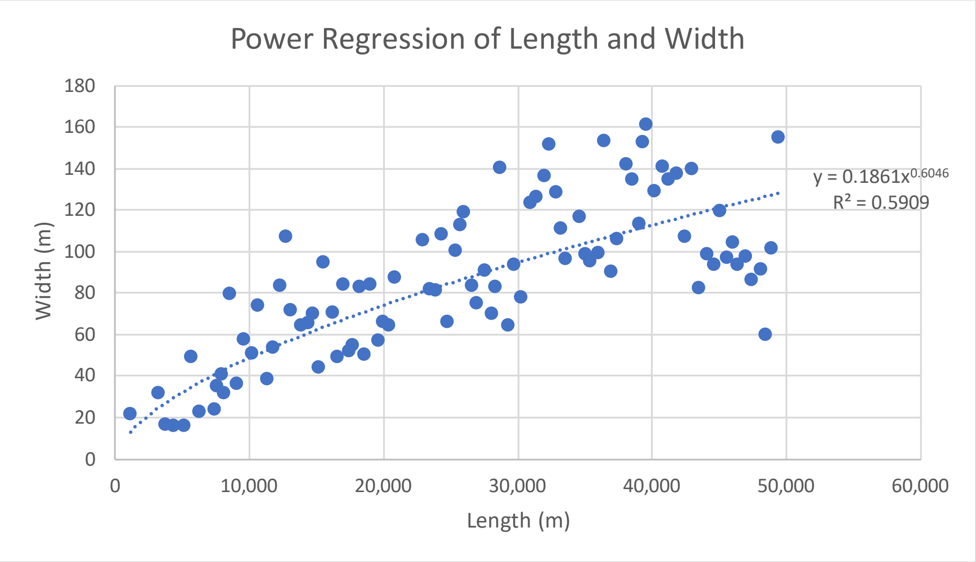


Figure 5.4 Regression Formula for Length and Width

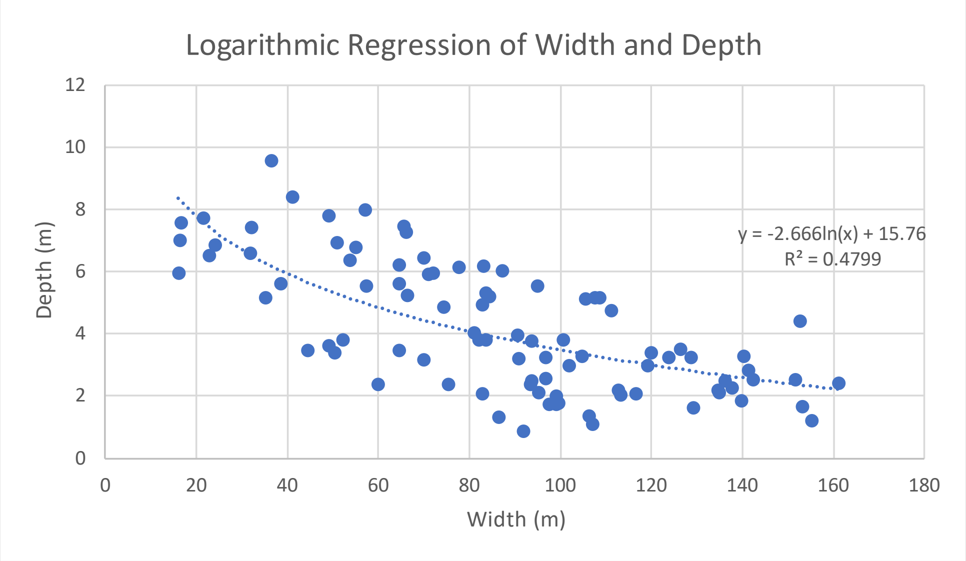


Figure 5.5 Regression Formula for Width and Depth

Regarding the levees, the height was calculated by the average differences between DTM and cross-section data for each levee segment. However, the initial simulation results show multiple locations of river overflow on the top of the levee. It is because the levee built in the model is superimposed on the DTM by assigning a height value, but the resampled DTM does not have consistent elevation along the levee line. There are some lower elevations on certain parts of the levees when using average values to overlay on DTM, causing gaps for water overflow at the top of the levees. Therefore, instead of using average values for levees elevation, it was decided to enhance the lowest levees' elevation in the model in such a way that it is higher than that part in the cross-section's elevation.

5.2.4. Dam Discharge

In the Tsengwen River basin, there are three reservoirs, and two of them have an influence on the flood simulation area. The reservoirs were constructed not only for water supply but also for regulating floods by controlling the time and amount of water released downstream. The discharge of the dam has a significant effect on downstream floods, so it cannot be ignored in the flood modelling. The Tsengwen Reservoir was constructed with three control gates for releasing water to the spillway. On the other hand, the Nunhau Reservoir was built with a free overflow spillway. Two different approaches were taken to model the dams' discharge. The upstream catchment of the Tsengwen Reservoir and the Tsengwen Dam was not modelled but used the historical discharge record to impose at the entry point of the river. The discharge data (hourly) was provided by stakeholders (figure 5.6). Regarding the Nunhua Reservoir, the entire catchment of the dam was modelled. The outflow of the dam was adjusted by modifying the DEM to let the behaviour of the simulated discharge outflow is similar to the observed outflow.

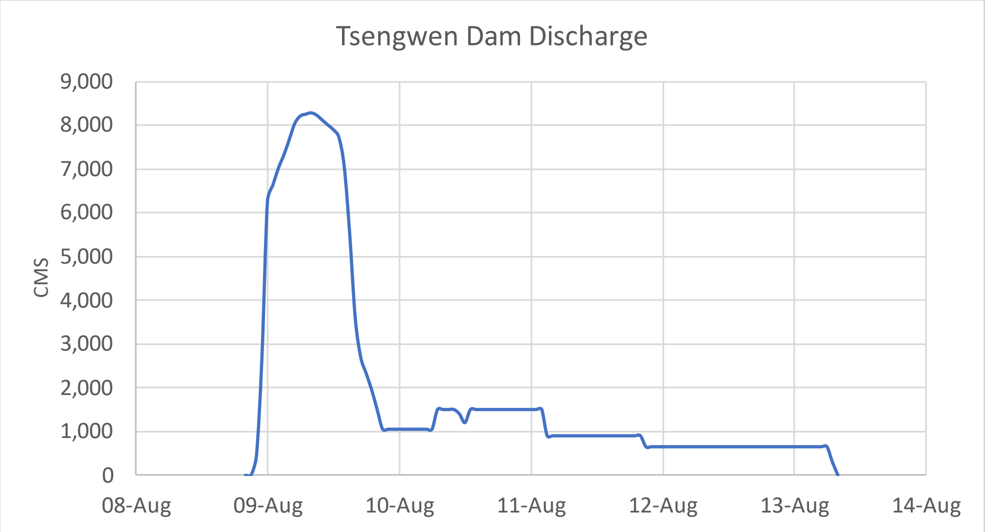


Figure 5.6 Released Discharge Record from Tsengwen Dam in Morakot Event

a. Tsengwen Reservoir Spillway[7] b. Nunhua Reservoir Spillway[8]

Figure 5.7 Spillway of Tsengwen and Nunhua Reservoir

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[7] https://news.ltn.com.tw/news/life/breakingnews/3626437
[8] https://news.ltn.com.tw/news/life/breakingnews/3587009

5.2.5. Land Cover

The land cover was converted from the land use map produced by the National Land Surveying and Mapping Center. The land use map is updated every two years (urban area) or five years (forest area) based on the latest orthophoto. The land use map, which has 57 categories, was used for generating the land cover map (figure 5.8). The comparison table of the conversion is shown in Annex 2. There are 14 types of land cover in the modelling domain. The major land cover type in the area is orchard, with 31.59%, followed by mixed forest and bamboo forest, representing 27.59% and 13.3%, respectively. Each land cover type was assigned Manning's n value, which used the suggested mean value from the Hec-Ras 2D modelling manual (2023) to represent the roughness of the surface. The assigned Manning's n shows in table 5.3, and the other parameters of land use are listed in Annex 3. However, some land cover types do not exist in the Hec-Ras manual. For those land cover types without suggested value, their value was assigned based on the understanding of the land surface condition and compared to the others' suggested land cover value.

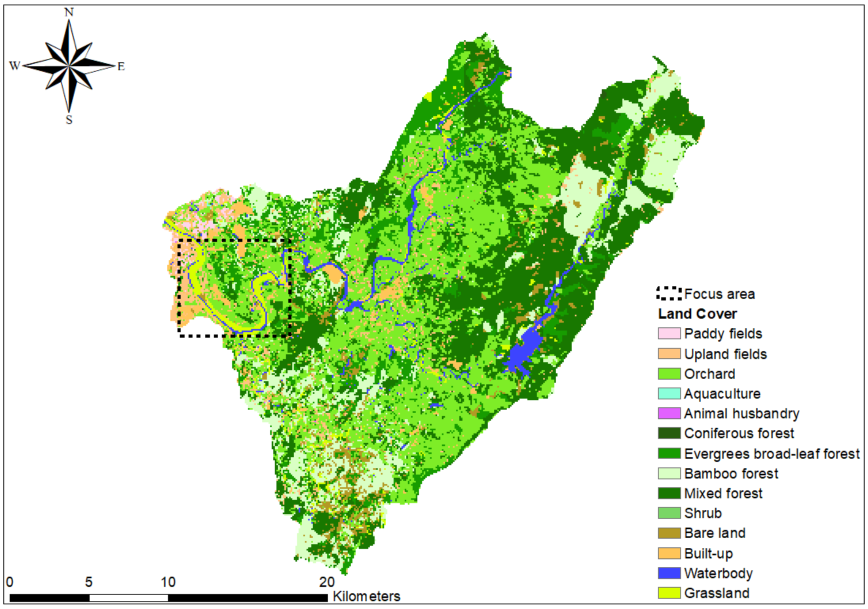

Figure 5.8 Land Cover Map for Model Simulation

Table 5.2 Manning's n Value and the Coverage Percentage for Each Type of Land Cover

Land Cover	Suggest n value range	Assigned n value	Percentage
Paddy fields	N/A	0.1000	0.50%
Upland fields	0.020 - 0.05	0.0350	3.67%
Orchard	N/A	0.0788	31.59%
Aquaculture	0.025 - 0.05	0.0375	0.03%
Animal husbandry	N/A	0.0320	0.06%
Coniferous forest	N/A	0.1200	0.05%
Evergreen broad-leaf forest	0.08 - 0.16	0.1200	11.48%
Bamboo forest	N/A	0.1500	13.30%
Mixed forest	0.08 - 0.20	0.1400	27.59%
Shrub	0.07 - 0.16	0.1150	0.03%
Bare land	0.023 - 0.030	0.0265	3.82%
Built-up	0.12 - 0.20	0.1600	2.82%
Waterbody	0.025 - 0.05	0.0375	2.76%
Grassland	0.025 - 0.05	0.0375	2.31%

5.3. Calibration

Calibration is the procedure for ensuring the model behaviour is as similar to the real world as possible. By adjusting the parameters in the model, the simulation result is compared to the observation data by some metrics. The aim of the calibration process is to tune the model parameters to improve the correspondence between predictions and observation. Nash–Sutcliffe efficiency (NSE) is one of the widely used metrics for calibration in hydrological modelling. The squared-error nature of NSE makes it emphasizes the high flow estimation (Mizukami et al., 2019). The NSE is selected because this study focuses on the high-flow behaviour of the flood. Calibration NSE is typically regarded as acceptable in the literature if it is greater than 0.6 and excellent if it is greater than 0.8 (Umer et al., 2021).

$$NSE = 1 - \frac{F}{F_0} \quad (where\ F = \sum_{n-1}^{N}(Q_{obs} - Q_{sim})^2 \ and\ F_0 = \sum_{n-1}^{N}(Q_{obs} - \overline{Q_{obs}})^2$$

The Tsengwen River Bridge discharge station, located downstream of the focus area, was used for the final model calibration. The calibration period is selected from the beginning of the rain till the end of it (August 4th to 19th). Before starting the calibration process, the initial soil moisture content was set to between field capacity and fully saturated because there were several small rainfall events in July (before the Typhoon Morakot event), which made the soil become relatively wet.

With regard to the calibration process, it is based on the understanding of the hydrological cycle and the structure of the OpenLISEM model. It can be briefly divided into two phases. The first phase compares the differences between the simulation curve and the observation curve visually. After the observation and simulation curve are visually matched, the next phase is fine-tuning. Fine-tuning means changing parameters one-by-one to minimize the error of peak discharge and maximize the NSE value. The discharge curve can be simplified into three parts: the climbing curve, the peak, and the declining curve. The value of theta refers to the initial moisture content of the soil and has a significant impact on when the discharge starts rising up. In addition, the Ksat (hydraulic conductivity) also has an influence on it because this parameter dominates the capacity of soil to infiltrate water. Regarding the peak value of the discharge curve, the thatai also has a crucial role in it because it affects how much water can be infiltrated. The channel manning's n value also plays an important role here. The Manning's n value of the channel represents the roughness of the channel bed, so it dominates how fast water flows through the channel. In this catchment, tuning the n value lower makes all the branches' water accumulate together faster and make a higher peak and more fluctuated curve (easier to respond to rainfall).

There are other parameters that can be adjusted in the OpenLISEM, for example, the surface Manning's n value, interception storage (Smax), surface micro-roughness (RR), etc. The Smax and RR parameters were not used for calibration in this study because these two have a relatively minor impact on the discharge regards to this kind of typhoon event. About the surface Manning's n value, it is also an important parameter to the model behaviour. However, it was not used for two reasons. First, the model already has good performance after being calibrated by theta, Ksat, and channel Manning's n. Second, the impact of surface Manning's n on the model discharge is related to other parameters' settings.

The calibrated parameters' values are listed in table 5.3, and the calibrated result is demonstrated in figure 5.9. The green line is the historical discharge record, and the orange line is the simulation discharge. The line chart on the top shows the average rainfall in the Morakot Typhoon event. Regarding the discharge peak, there is only 0.03% absolute error, and the NSE value is 0.938, which verifies that the model has an excellent performance.

Table 5.3 Calibration Result of Important Parameters

Parameters	Range of values in the input maps	Calibration multiply factor
Thatai 1	0.372 – 0.514	0.97
Thatai 2	0.37 – 0.46	0.97
Ksat 1	0 – 39.5	0.95
Ksat 2	0 – 14.8	0.95
Channel manning’s n	0.03	1.35

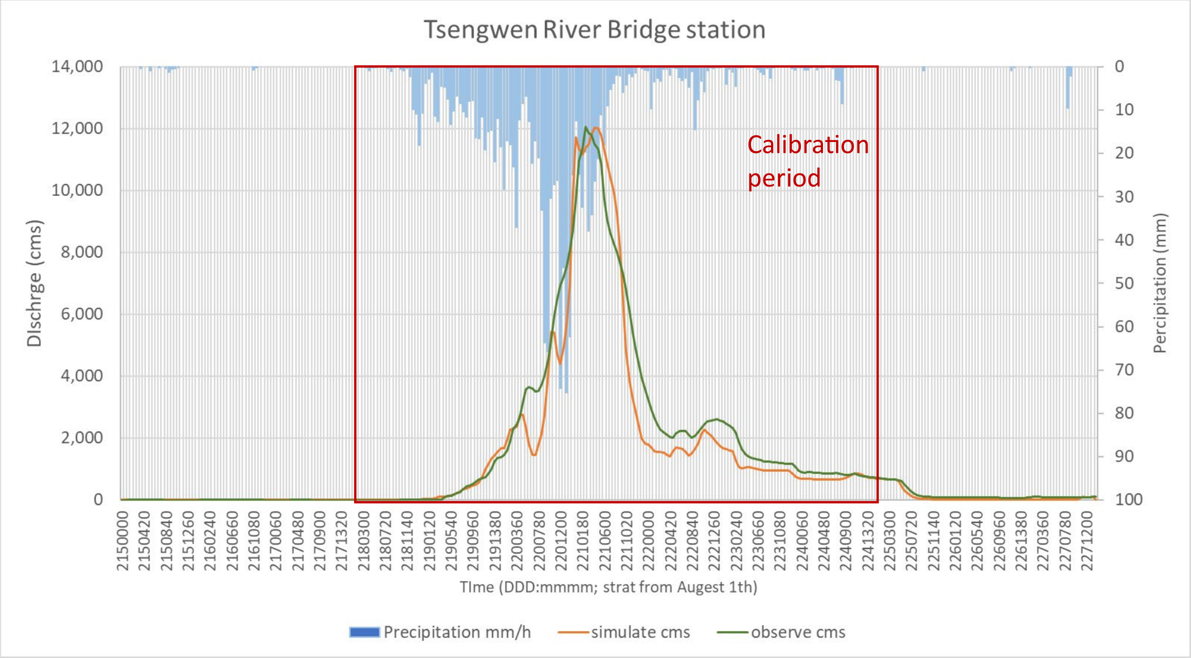

Figure 5.9 Calibration Result on Discharge Curve

6. QUESTIONNAIRE DESIGN FOR SEMI-STRUCTURED INTERVIEW

The questionnaire was developed based on the elements of Contextual Interaction Theory (de Boer, 2012), the Flood Resilience framework (Hegger et al., 2016), and the proposed RftR interventions. The questionnaire consists of four parts: 1. Perception of Taiwan's flood risk management; 2. Water governance; 3. Room for the River designs; 4. Flood resilience. The interview questionnaire has two versions; one is for government servants, and the other is for experts. Some questions are different from the government servants and experts because they normally play the opposite role in the water governance system.

Table 6.1 illustrates the corresponding of the questions to the frameworks' elements. The purpose of this design is to gain knowledge from the stakeholders with a focus on the target points. In addition, these frameworks also contribute to organizing interview feedback in the order of the frameworks' logic.

Table 6.1 Corresponding Interview Questionnaire with Frameworks

Num	Questions	CIT	Flood Resilience
Part A. Perception on flood risk management			
1	It is recorded that the natural riparian was dramatically lost after Typhoon Morakot (lots of levees were built). What do you think is the driver of this phenomenon?	Wider content / Cognition	Capacity to resist
2	What are your most concerned issues in the current trend in Taiwan's water-related management issues (e.g., Floods, drought, ecology, etc.)?	Motivates	-
3	Do you think the water governance system has changed in the past decades based on the experience of floods (e.g. cooperation of governments, regulations or laws, strategies for flood risk management)?	Structural content / Cognition	Capacity to adapt and transform
4	What kind of pressure will you face when the floods occur? (only for government servants)	Motivates	-
Part B. Water governance (Experts)			
1	Have you been invited to the evaluation committee in the water management project or during the policy-making process? To what extent do you feel your opinion and advice have been accepted?	Resource	Capacity to adapt and transform
2	What is your experience when working on a water management-related project with the government? (e.g. Do you think you have mutual communication? Do you find the conflict between your research and government demand?)	Motivates / Resource	-
3	Who do you think should be responsible for the damage from floods and who have the responsibility to take action in response of floods?	Motivates	-
4	What kinds of support should the government provide citizens to prepare for and recover from the flood threat (e.g., compensation, labor help for clean-up)?	Structural content	Capacity to absorb and recover

Part B. Water governance (Government servants)			
1	How are flood risk management projects formed, and how was the final decision made (who is involved)?	Resource	Capacity to adapt and transform
2	Who do you think should be responsible for the damage from floods and who have the responsibility to take action in response of floods?	Motivates	-
3	What is the standard operation process of the preparation for floods in the flood risk response system?	Structural content	Capacity to absorb and recover
4	What kinds of support are provided by the government to citizens to prepare for and recover from the flood threat (e.g., compensation, labor help for clean-up)?	Structural content	Capacity to absorb and recover
Part C. Room for the River Designs One of the innovative thoughts of the Room for the River approach is designing interventions horizontally but not vertically, while also ensuring the spatial quality of the riverine. The RftR approach might need extra land for floods or multiple purposes. For example, it can assign some agricultural areas to be flooded to reduce the damage of build-up areas.			
1	What do you think about the potential opportunities and obstacles to implementing the Room for the River (RftR) in Taiwan? (e.g., policy tools or restrictions for compensation, reclaiming land, protection standard, etc.)	Structural content	Capacity to adapt and transform
2	As shown in the intervention designs in the focus area. What do you think are the most preferred/possible interventions to be implemented in the focus area? Why?	Specific content	Capacity to resist / Capacity to absorb and recover
3	The dual-objective of RftR includes reducing flood risk and improving spatial quality, which often infers the multiple-function use of the land. What do you think is the most possible land-use design in the created floodplain area (e.g. recreation, agriculture, ecological wetland)	Specific content	Capacity to resist / Capacity to absorb and recover
4	To what extent do you think Taiwan's society is ready to adapt the flood risk management methods to the international concept or trend, such as RftR (regarding the money, skilled people, technique, consensus, etc.)?	Wider content / Cognition	Capacity to adapt and transform
Part D. Flood resilience			
1	"Building flood resilience for paradigm shift" is one of the conclusions of the National Water Governance Conference in 2019. Could you briefly define flood resilience in the flood risk management content?	Structural content / Cognition	-
2	What kinds of measure do you think can contribute to enhance flood resilience?	-	All (based on the response)
3	What is your opinion of constructing flood defense engineering (higher levees, drainage systems, etc.) to prevent the area from floods as the main measure?	Specific context / Cognition	Capacity to resist
4	To what extent do you have confidence that the levees can protect the area from floods in the future, especially under the threat of climate change?	Cognition	Capacity to adapt and transform

7. ROOM FOR THE RIVER INTERVENTION DESIGNS

7.1. Riverine Characteristics in the Focus River Segment

The focus river segment has been constricted by levees since the 2000s. Figures 7.1 and 7.2 demonstrate the narrowed river floodplain by comparing the historical images. Levee has recognized its negative impact on the social-ecological context. This structural measure reduces the floodplains' ability to naturally store floods, enhance water quality, provide habitat for fish and invertebrates during flooding, and provide a wide range of cultural functions (Serra-Llobet et al., 2022). Moreover, the high-rise levee causes more flood-related losses if a failure occurs, and the false feeling of security might unintentionally encourage investment in flood-risk areas (Sanyal, 2017). In addition, the dam's construction might decrease the supply of bedload sediment and cause a shift in the channel pattern. The interruption of sediment transport makes the flow become sediment-starved (hungry water) and susceptible to eroding the channel bed and bank, resulting in channel incision (Kondolf, 1997). The transportation of sediment in the Tsengwen River has been interrupted for half a century since the Tsengwen Reservoir was constructed in 1967. The cross-sections in figure 7.3, located at the focus river segment, shows deep channels that are likely downcutting.

Figure 7.1 River Image at the South-east of Danie District in 1975 and 2023[9]

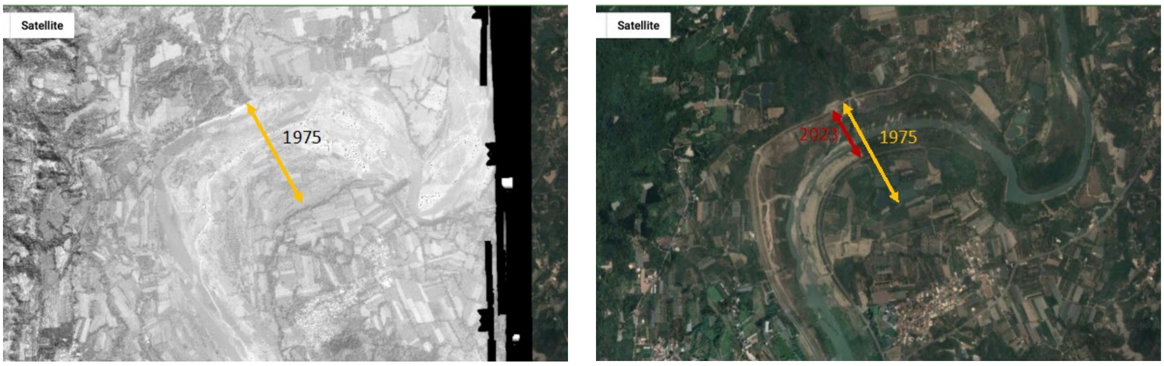

Figure 7.2 River Image Upstream of Danie District in 1975 and 2023[10]

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[9] https://gissrv4.sinica.edu.tw/gis/tainan.aspx
[10] https://gissrv4.sinica.edu.tw/gis/tainan.aspx

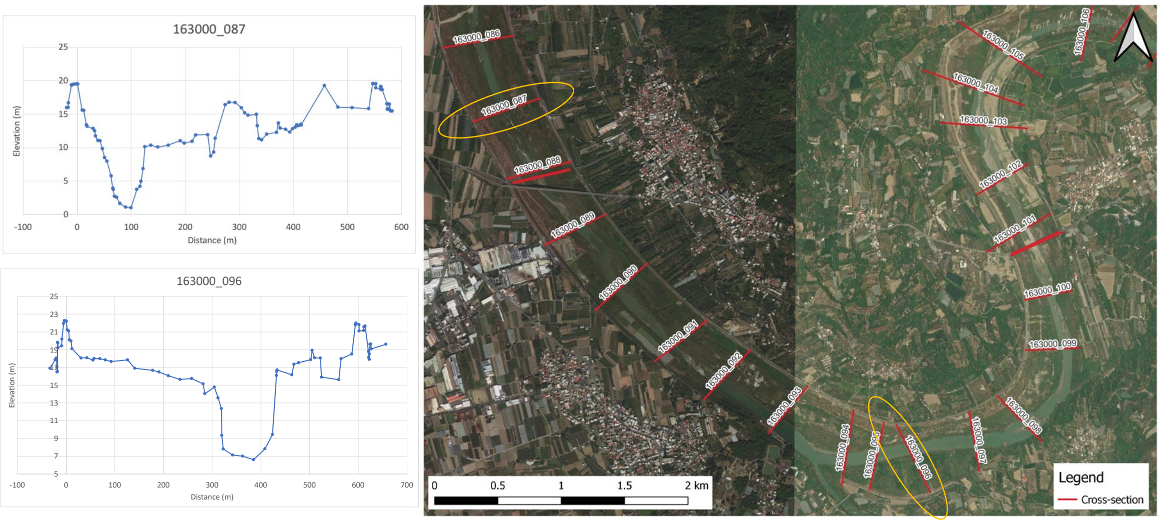
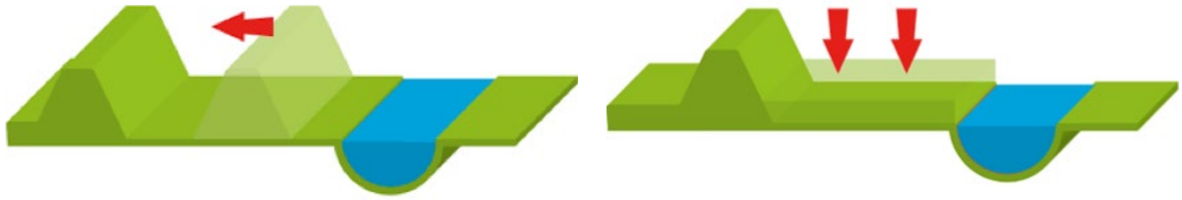


Figure 7.3 Channel Incision in the Focus River Segment

7.2. Selected Room for the River Approaches and Reference Cases in the Netherlands

As mentioned in Chapter 3, the innovation of room for the river is that the designs focus horizontally but not just strengthening the levees vertically. Based on the characteristics of the focus area, dyke relocation (figure 7.4a) and excavating/lowing floodplain (figure 7.4b) were selected as the design approaches. These two approaches can also be seen as river restoration and floodplain restoration measures, which often attempt to restore the hydrological, ecological, and geomorphologic processes of rivers (Juarez Lucas & Kibler, 2016), also can be recognized as NbS measures (Provan & Murphy, 2021; Ruangpan et al., 2020).



a. dyke relocation b. lowering/excavating floodplain

Source: Rijkswaterstaat[11]

Figure 7.4 Selected Room for the River Approaches

With regard to other RftR approaches, lowering the summer bed was not used due to the Tsengwen River already having the issue of channel incision. Removal of obstacles and height reduction of groynes are not applicable because there is not too much infrastructure in the river channel. Concerning the false security that might reduce the community's resilience to floods, the heightening of the dike and dike improvement are put into the design. The bypass and water retention are not used because the focus area doesn't have a vast open and flat space for these interventions.

Although the dual-objective of RftR includes reducing flood risk and improving spatial quality, not all the projects were marked to meet the latter goal (Busscher et al., 2019). The Room for the River projects at Nijmegen (Ruimte voor de Waal) and Deventer (Ruimte voor de Rivier Deventer), which are assessed as sufficient for spatial quality improvement by Busscher (2019), are the reference case studies for the intervention design. The Room for the River in Nijmegen is an example of dike relocation. The River Waal

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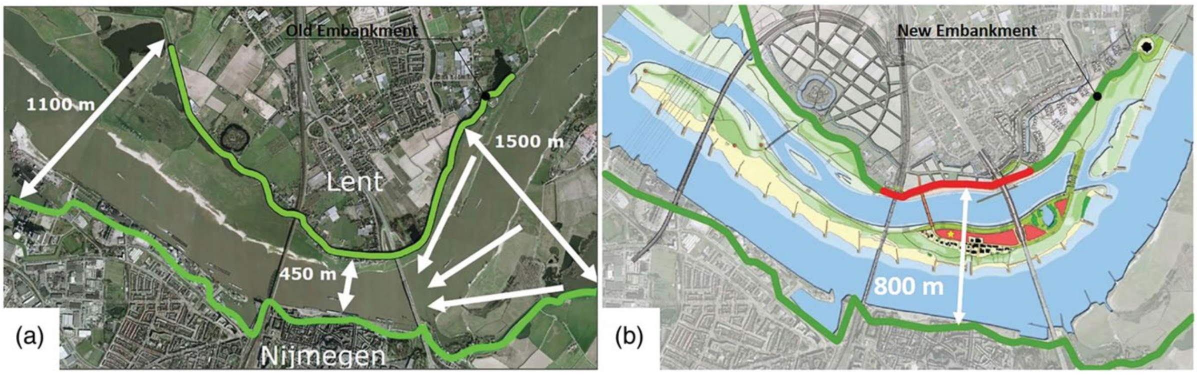
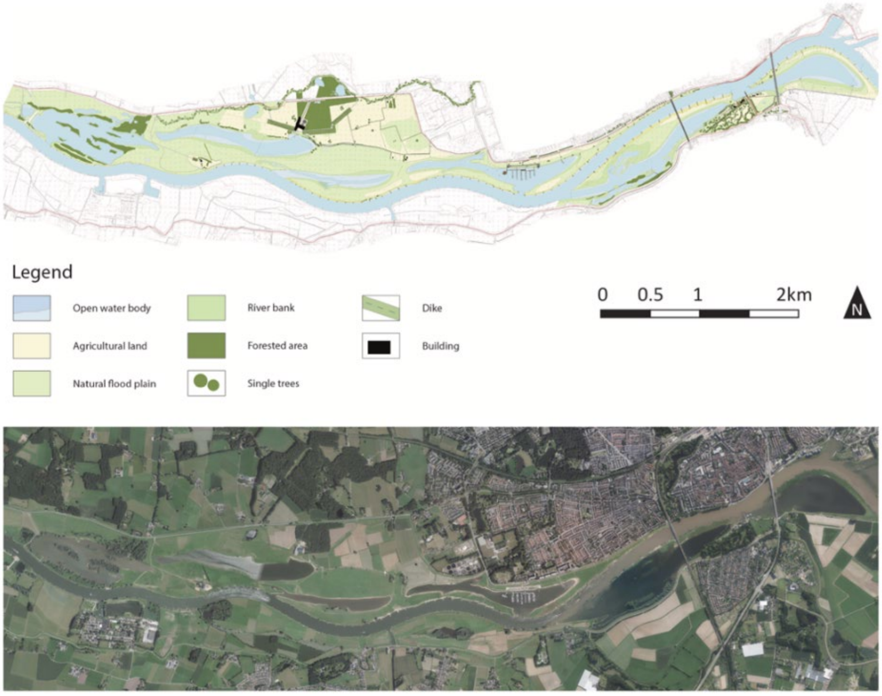
[11] https://www.rijkswaterstaat.nl/en/water/water-safety/room-for-the-rivers/measures-in-and-around-rivers

is particularly narrow between the cities of Nijmegen and Lent, which was considered a bottleneck in the river system (Edelenbos et al., 2017). As shown in figure 7.5, the embankment was relocated inland around 350 meters at the village of Lent (Rădulescu et al., 2021). The project also ensures not only the spatial quality for better ecological connectedness of the floodplain ecosystem but also the great recreation potential (Klijn et al., 2013). The project in the Deventer is the showcase of lowing and excavating floodplains. As figure 7.6 shows, there are several spatial measures on the riverside. The floodplains near the city of Deventer were widened and lowered to provide the Ijssel River with more space during the high-water period (van den Brink et al., 2019).



Source: Yu (2020). (a) Before implementation. (b) After implementation

Figure 7.5 Room for the River in Nijmegen



Source: van den Brink (2019)

Figure 7.6 Room for the River in Deventer

7.3. Designed Interventions

Based on the lesson in the Netherlands and the characteristic of the focus area. Three designed RftR interventions were developed. Figure 7.7 demonstrates the intervention designs in the focus area. The green line is the current levees. The red lines are the proposed setback levees intervention, which is based on the historical floodplain extent area. The blue polygons are proposed for excavating floodplain intervention, which is suggested to design as retention ponds. The yellow polygon is the intervention of lowing the whole floodplain because the area is easy for sediment deposits. These interventions were in discussion with the stakeholders in the semi-structured interview. The feedback from the interviewees is used as one of the flood modelling scenarios in section 7.2.

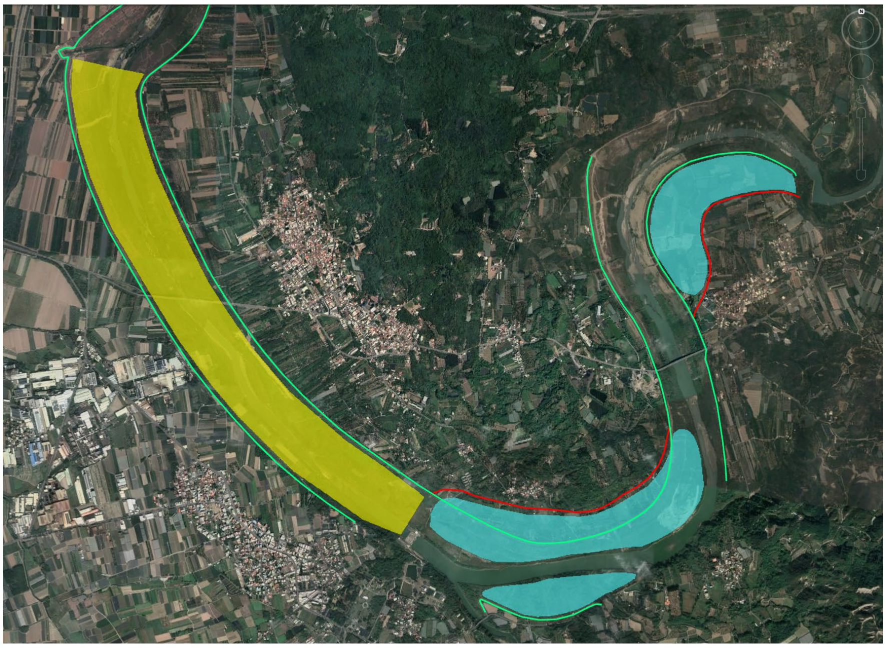


Figure 7.7 Proposed RftR interventions

8. FLOOD MODELLING ANALYSIS RESULT

8.1. Floods Characteristic in the River Segment

The flood characteristic in the Tsengwen River basin is complicated. To analyse the discharge composition, the modelling domain was split into three sub-catchments. Three outlet points were assigned in the OpenLISEM to extract the flood simulation's discharge information. Figure 8.1 demonstrates the sub-catchment area, the location of discharge outlet points and the reservoir discharge inlet points. The upstream catchment of Tsengwen Reservoir is massive, so it plays an important role in regulating downstream floods. The Tsengwen Reservoir catchment represents 38.7 % of the whole Tsengwen River basin area, and the upstream catchment area is 87.3 % as large as the area of the modelling domain.

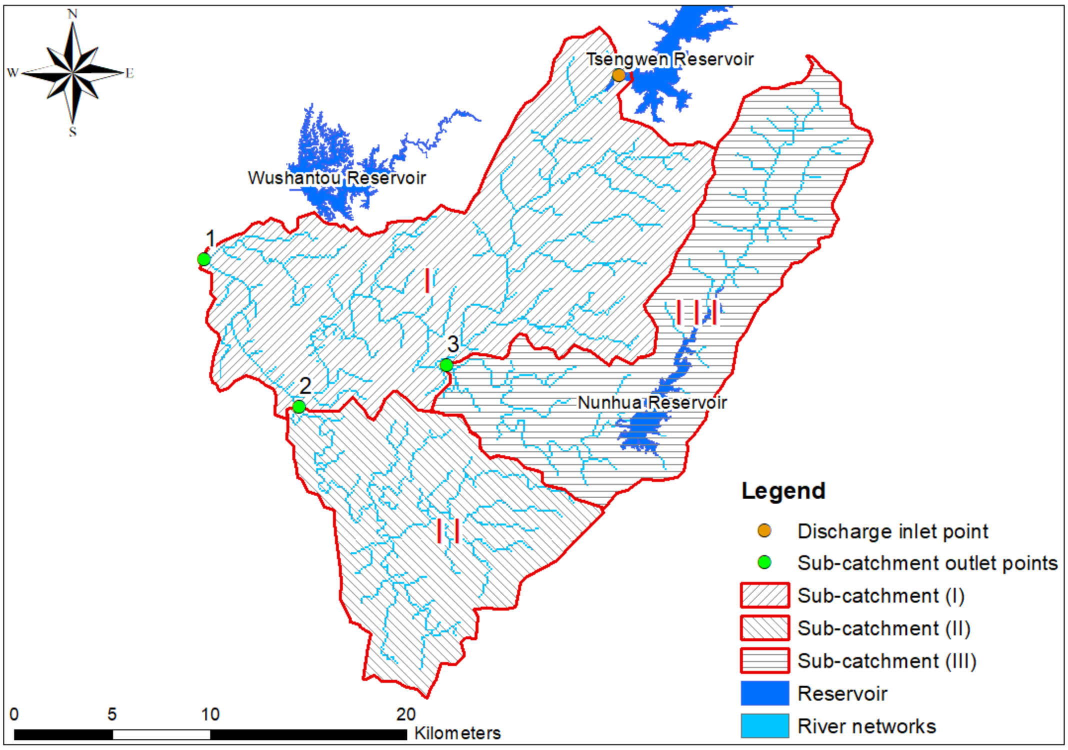
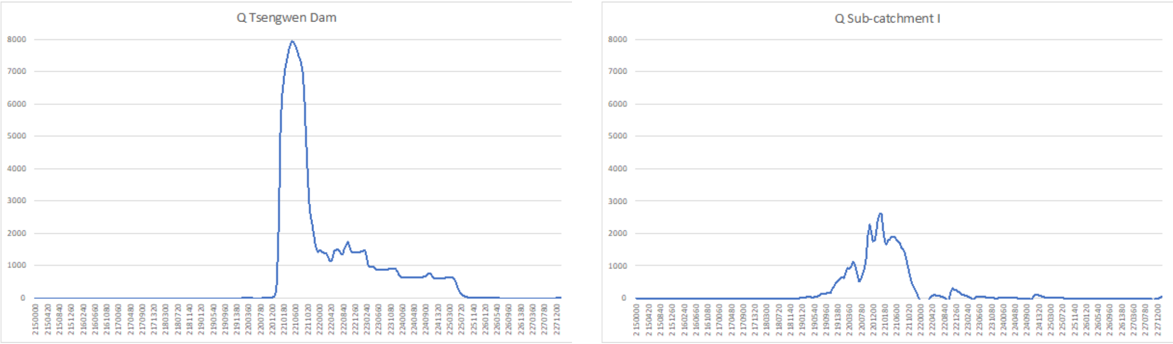


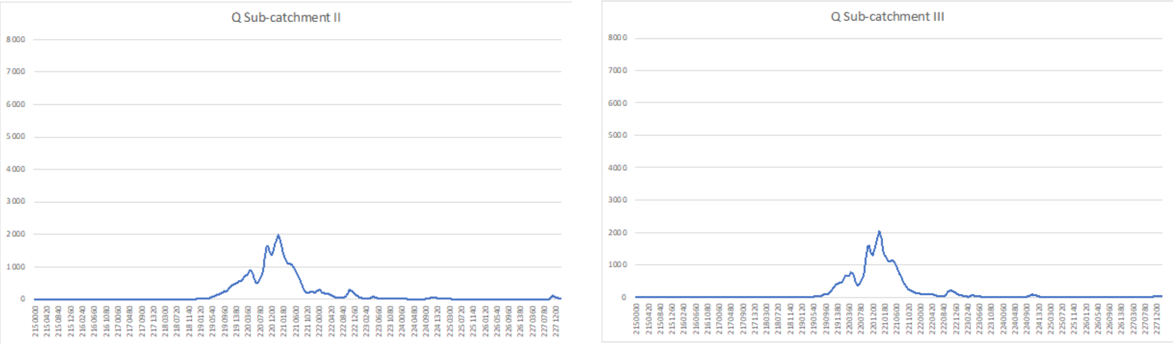
Figure 8.1 The Setting of Discharge Composition Analysis

The discharge composition analysis is based on the data from two simulations (with and without dam inlet discharge). The discharge difference at point 1 (see figure 8.1) between the two simulations revealed how the impact of dam discharge on the downstream (shown in figure 8.2a). Subtracting the discharge at point 2 and point 3 from point 1 yields the discharge of sub-catchment I (see figure 8.2 b). Figure 8.2 c and figure 8.2 d represent the discharge of sub-catchment II and III, respectively.

Figure 8.3 is the accumulation curve of the four discharges in figure 8.2, which demonstrates the flood discharge composition from the Tsengwen Reservoir and three sub-catchments. The discharge from Tsengwen Reservoir represented significant amounts of water in the channel. Moreover, the graph in figure 8.3 shows that the Tsengwen Reservior played a crucial role in regulating the peak flow in the Typhoon Morakot event. It delayed the discharge peak from the Tsengwen Reservoir catchment to avoid the peak coming simultaneously with other sub-catchments.

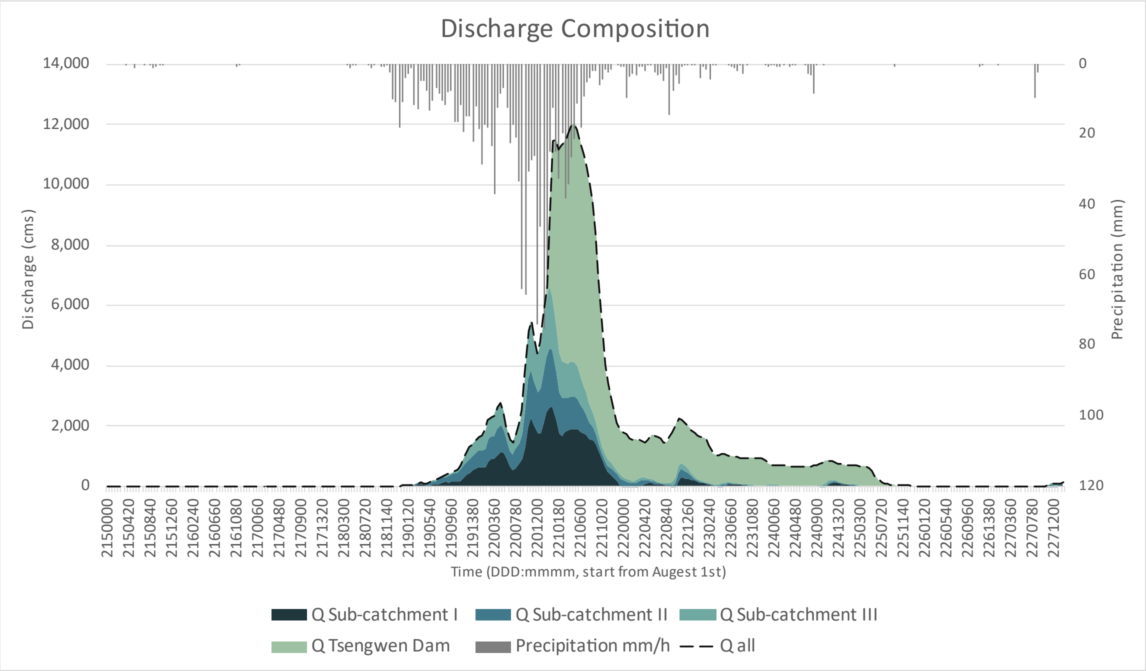


a. discharge from the Tsengwen Dam b. discharge from sub-catchment I



c. discharge from sub-catchment II d. discharge from sub-catchment III

Figure 8.2 Discharge from the Tsengwen Dam and sub-catchements



Note: The Tsengwen Dam caused the peak shift in the Morakot event.

Figure 8.3 Flood Discharge Composition from Different Sub-catchments

8.2. Assessing the Effectiveness of Different RftR Interventions

This section is going to explore the efficiency of the implementation of different RftR interventions. The following four scenarios were simulated with the rainfall in the Morakot event. Besides the calibration (figure 8.4 point A), there are two more points for assessing the effect of the intervention. One is located on the Danie Bridge (point B), and the other is located upstream of Danie District (point C). According to the interviewees, the levees near these two points have a higher potential to be overtopped or broken by floods. The RftR intervention designs are demonstrated in figure 8.5.

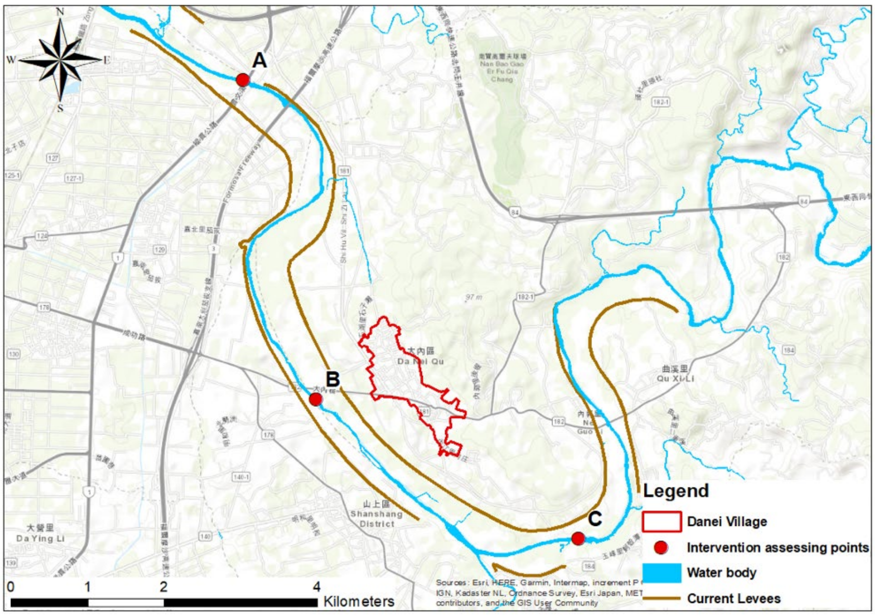
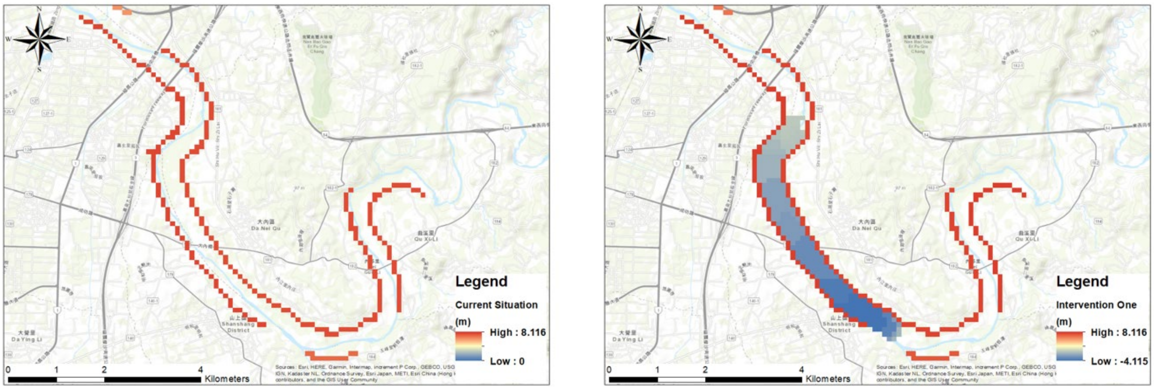
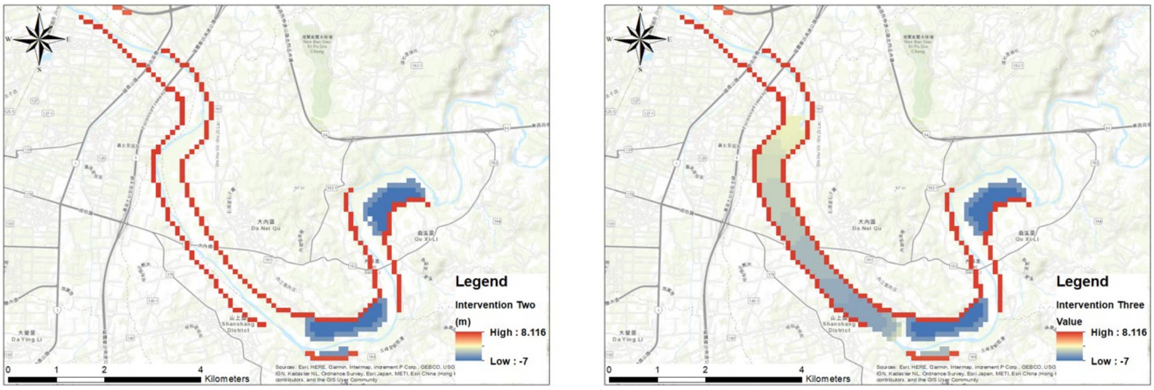


Figure 8.4 Points for Assessing Intervention Effectiveness



a. current situation b. intervention one



c. intervention two d. intervention three

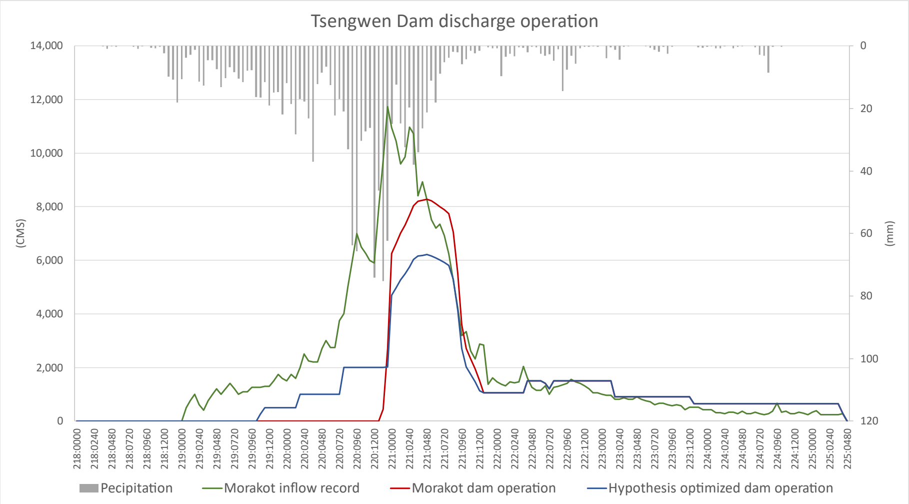
Figure 8.5 RftR Intervention Designs

As mentioned in section 5.2.2, there is a limitation in the OpenLISEM to build levees in the model because the levees are built by overlaying the assigned height on the DTM elevation. In the study, the levees built in the model were enhanced to the level that water won't overflow the top of them. This assumption is reasonable because the current protection standard of designed discharge in the focus Tsengwen River segment is one hundred years return periods with 12,500 CMS capacity, and the simulated discharge is within this capacity. The first setting is to simulate the structure of the current levee (figure 8.5a).

The first RftR intervention, designed as lowing the floodplain with the structure of the current levees, is shown in figure 8.5b. This intervention is recognized as the easiest one to implement under the current water governance system by most of the interviewees because the Water Resources Agency has the power to apply intervention measures within its management authority domain (area within the levees). According to the interviewee who works in the Sixth Office of the Water Resource office, digging down the floodplain for three to five meters is possible in this river segment. Based on this information, the intervention of lowing the floodplain is made by digging the floodplain from 0.5 meters downstream of Danie District to 4.2 meters gradually.

The second RftR intervention (figure 8.5c) is designed to setback existing levees to the edge of the historical floodplain extent area. The created space on the floodplain is designed to modify as retention ponds, as shown in figure 7.7. The maximum depth of the retention ponds is 7 meters based on the constructed retention pond along with the riverbank downstream. The third intervention (figure 8.5d) is a combination of interventions from the previous two. The aim is to explore the effectiveness of all the proposed RftR interventions are implemented.

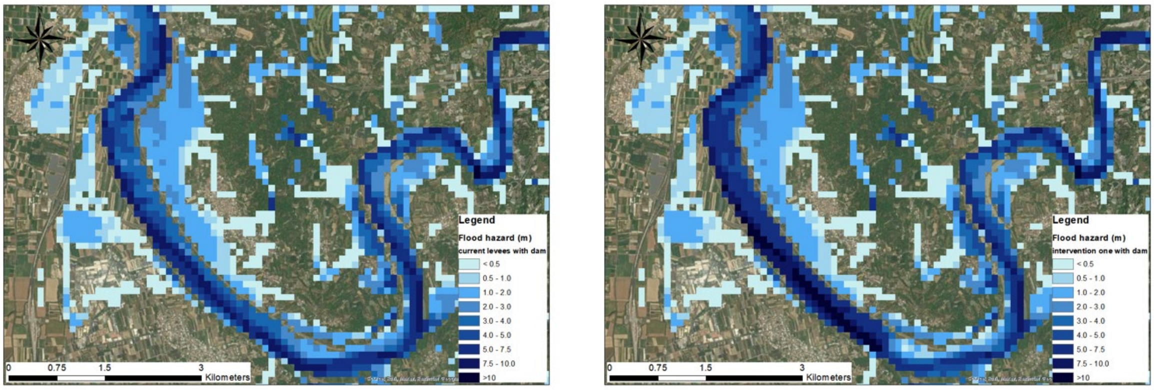
The fourth intervention is not RftR design. It was developed to explore the effect of dam operation on the downstream. Since the dam discharge operation is crucial to the downstream flood in the Tsengwen River, this intervention explores how the different dam operations can influence the downstream discharge. As shown in figure 8.6, the hypothesis-optimized dam operation intends to respond to the inlet discharge earlier and reduce the peak of released discharge. In the optimized dam operation, the released discharge is triggered to release half of the inlet discharge at the inlet to reach 1,000 CMS, 2,000 CMS, and 4,000 CMS. When the inlet discharge reaches over 10,000 CMS, the operation releases three-quarters of the record Morakot dam discharge. After the inlet is lower than 2,000 CMS, the optimized dam operation follows the historical operation record. The total amount of discharge between the optimized dam operation and historical operation is approximated the same.



Note: The blue line has the same volume but an earlier release compared to the red line

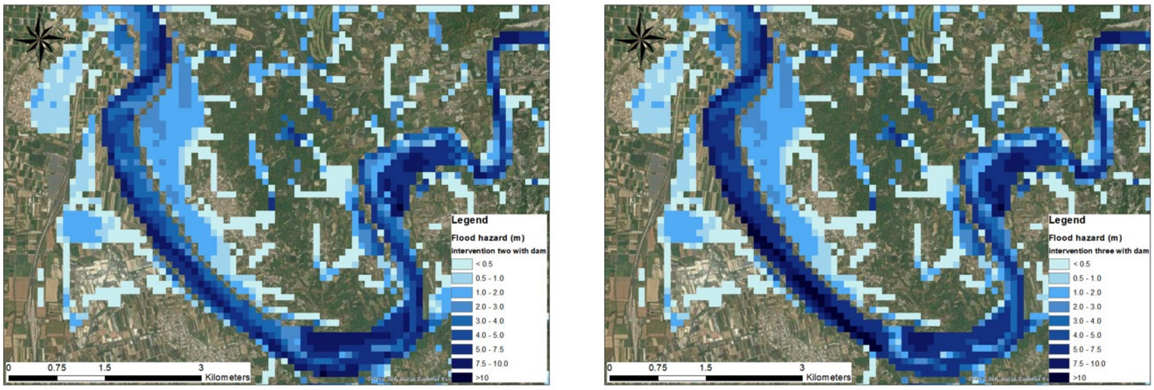
Figure 8.6 Comparison of Dam Discharge Operation.

The aforementioned RftR interventions are simulated with and without dam discharge in the Morakot event's precipitation. In addition, the hypothesis optimized dam operation intervention is simulated in Morakot rainfall scenarios. The simulated flood hazard results for each intervention are exhibited in figure 8.7 and figure 8.8. The change in peak discharge in the channel and water height are listed in table 8.1 and table 8.2. The results show that in both scenarios (with or without dam discharge), the RftR intervention can drop the water height by 5-7 cm and curb the discharge for around 80 CMS. In addition, the optimized dam operation can mitigate the flood discharge by reducing 1835 CMS and decreasing channel water height by more than 1.5 meters.



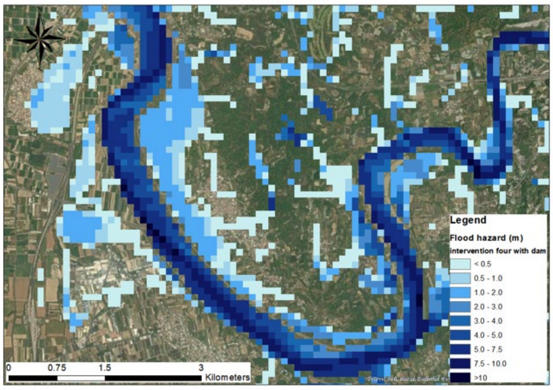
a. current levees with dam discharge

b. intervention one with dam discharge



c. intervention two with dam discharge

d. intervention three with dam discharge

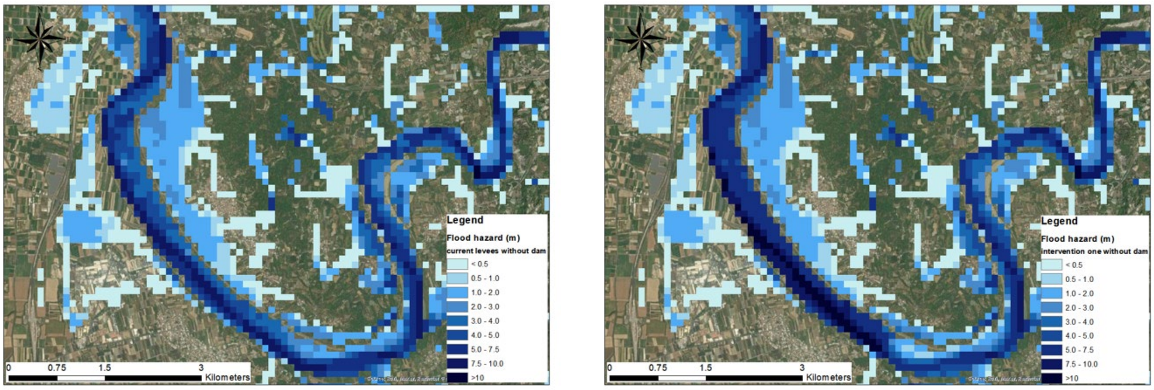


e. intervention four with dam discharge

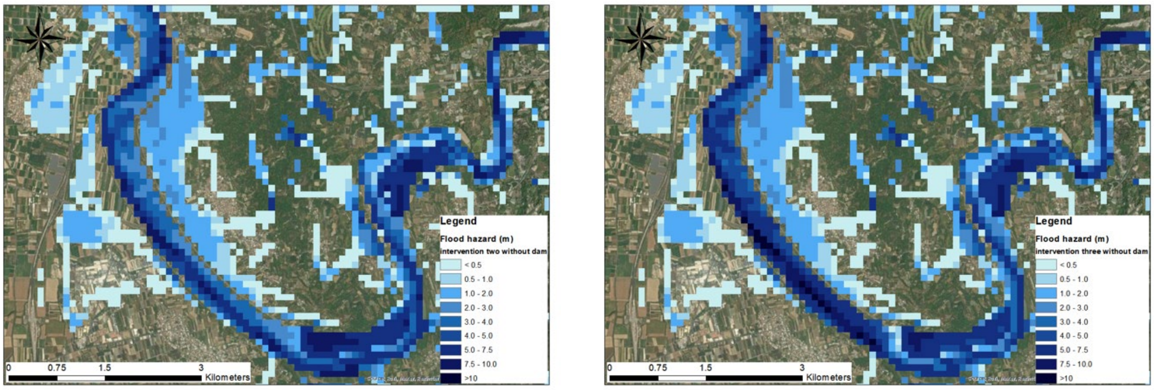
Figure 8.7 Flood Hazards with Dam Discharge in Different Interventions

Table 8.1 Comparison of the Effectiveness of Interventions in Rainfall and Dam Discharge Scenarios

Intervention	Peak discharge (CMS) / channel water height (m) at Point A	Peak discharge (CMS) / channel water height (m) at Point B	Peak discharge (CMS) / channel water height (m) at Point C
current	12021.9 / 15.956	11831.7 / 12.453	10650.9 / 15.560
1	11970.5 / 15.913	11786.6 / 12.401	10624.3 / 15.534
2	12021.6 / 15.956	11838.4 / 12.459	10674.6 / 15.582
3	11943.3 / 15.891	11765.8 / 12.379	10624.7 / 15.532
4	10186.4 / 14.377	9997.4 / 10.820	8759.5 / 13.697



a. current levees without dam discharge b. intervention one without dam discharge



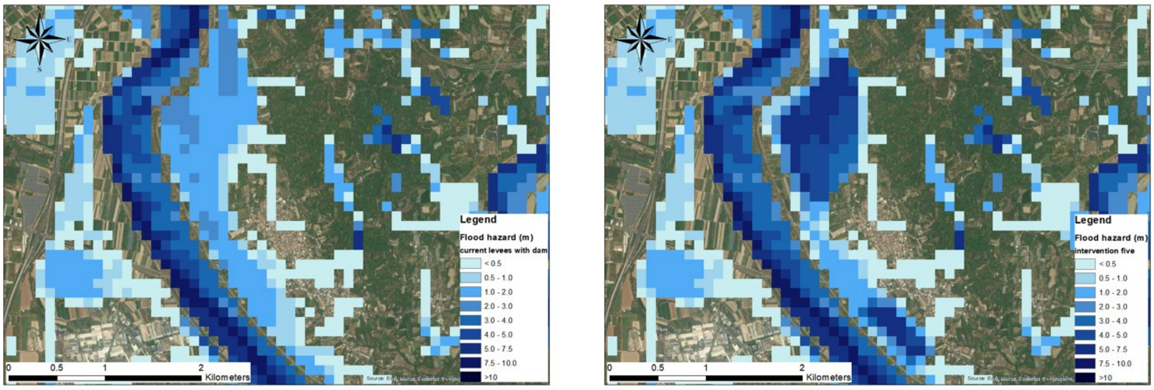
c. intervention two without dam discharge d. intervention three without dam discharge

Figure 8.8 Flood Hazards without Dam Discharge in Different Interventions

Table 8.2 Comparison of the Effectiveness of Interventions with Only Rainfall Scenarios

Intervention	Peak discharge (CMS) / channel water height (m) at Point A	Peak discharge (CMS) / channel water height (m) at Point B	Peak discharge (CMS) / channel water height (m) at Point C
current	6724.5 / 11.092	6516.1 / 8.299	4502.5 / 8.940
1	6647.3 / 11.013	6434.4 / 8.235	4469.8 / 8.897
2	6677.1 / 11.044	6471.3 / 8.264	4466.7 / 8.895
3	6656.4 / 11.022	6449.8 / 8.247	4451.3 / 8.874

In this intervention, detention ponds were designed on agriculture land near the Danei village. It is noticed that the floods in the Danei District are not from the river because the levees interrupt the connection between the floodplain and the land outside the levees. The floods might come from the northern mountain area runoff. During the high-water event, on the one hand, the gates of the drainage system to the main river are closed to prevent water from the main river flow to the built-up area. On the other hand, the construction of levees blocks the water flow from Danei District into the river channel and accumulates in the low-lying area in Danei District. This intervention uses the agricultural land for retention ponds to explore the change of flood hazards near the village. The maximum of the designed retention ponds is 5 meters. The results show in figure 8.9. Although the retention ponds accommodate lots of water, there is not too much change in flood extent after building the retention ponds near the village.



a. before building retention ponds b. after building retention ponds

Figure 8.9 Comparison of Flood Extent of Before and After Building Retention Ponds

9. ASSESSMENT OF INTERVIEWS RESULTS

9.1. Flood Resilience in Flood Risk Management

There are two important points to be aware of while using this flood resilience framework. Firstly, this framework was developed to combine the literature on engineering, ecological, social-ecological, and evolutionary flood resilience into three capacities. As Hegger (2016) mentioned, the desired outcome of a more flood-resilient country has to find the balance among these three capacities since there are potential trade-offs between these three capacities in flood risk management strategies. For example, investment in flood resistance can compromise flood resilience by decreasing the capacity to transform and adapt. As Liao (2012) argued, the flood control infrastructure hinders the chance of learning from frequent small floods to prepare the city for extreme ones; as a result, it erodes resilience. Secondly, it is worth noting that the framework is specifically designed for assessing resilience in flood risk management strategies; consequently, the role of residents is marginalised in this framework. This framework is selected because the interviews in this study focus on flood risk management strategies and cannot have field surveys or interviews with inhabitants. Instead, the interview data is obtained from the interviewees working in flood management. But it should also keep in mind that the success of flood management regards to the system's resilience is ultimately needed to land to inhabitants. Based on the feedback from the interviewees and the review of existing policies in Taiwan, the overall flood resilience assessment result for Taiwan's flood risk management is listed in table 9.1.

Table 9.1 Assessment of Flood Resilience Capacity in Taiwan's Flood Risk Management

Capacities	Assessment and description	
Capacity to resist	(+)	The National River Basin Governance Plan has already been completed with around 80-90% with 100-200 years of return periods protection standards.
	(+)	Have comprehensive historical knowledge and experience in constructing flood control infrastructure; in addition, the technique also keeps upgrading.
	(+)	Fewer floods caused by river flow over the levees in the past decade.
	(+)	The system has already implemented periodic monitoring and maintenance of flood control infrastructure.
	(+)	Flood storage/retention is in place and still developing. E.g. Xiwei retention pond in the Tsengwen River basin.
	(+/-)	Due to the resource exclusion caused by government organizational restructuring and the Special Budget Plan of 840 billion TWD in the past eight years for water related management, the recent budget of the Water Resources Agency has shrunk.
Capacity to absorb and recover	(-)	Slow implementation of urban retention due to the low motivation of the local governments.
	(-)	Natural riverine/floodplain is constricted because of the ambition of fulfilling the National River Basin Governance plan.
	(+/-)	There are regulations for flood damage compensation for private housing or agriculture; however, it is difficult to determine the compensation measure, and the money is minor compared to the damages.

	(+)	There is a regulation for incentive money for providing private land as flood detention.
	(+/-)	Early warning systems and intelligent water gauge sensors were built, but the residents have low flood awareness, so the information is hard to reach them.
	(+)	Over five hundred Self-organized Floods Disaster Prevention Communities have been built.
	(-)	Room for the River approach is discussed in the public, but the implementation is a limited extent.
	(+)	The procedure of the launch and preparation of Emergency Operations Centre for Disaster at every level of government has been well established.
Capacity to transform and adapt	(+)	Active NGOs advocate the international trend or concept of flood risk management to the government.
	(+/-)	The flood risk management strategies have some changes in the past decade but slow. Nevertheless, the actual paradigm shift from flood resistance to flood adaptation has still not yet happened.
	(-)	Conservative government organizations make it difficult to have significant policy changes.
	(-)	The flood control infrastructure limits citizen's experience with larger floods is likely to hinder the development of knowledge and innovations, as well as the awareness of flood risk.
	(-)	Limited citizen engagement in policy-making, with communication mostly being one-way.
	(-)	Despite there are effective top-down communication within government organizations, the communication and collaboration between different departments and disciplines are deficient.

9.1.1. Capacity to Resist

The capacity to resist floods is generally referred to as the measure of flood control infrastructure. In Taiwan, the history of hydraulic structures dates back over a hundred years since the Japanese colonial period, and the knowledge is inherited now. In recent decades, the flood control infrastructure has been well constructed in response to the several floods caused by typhoons in the 2000s. The National River Basin Governance Plan in the 26 national river basins has been completed to approximate 80-90 % with a protection standard of 100 to 200 years return periods. The interviewee, who is from the engineering company, observed that the technique of hydraulic engineering structure was upgraded in the 2010s. Most of the levees were strengthened by concreted-made material. With the construction of these flood control infrastructures, it was recorded that only a few flooding events resulted from the water over the top of levees or the failure of levees in the recent year.

The regular maintenance and monitoring of the infrastructure are also being outsourced to engineering companies to ensure the infrastructure is safe. In addition, several off-side retention ponds were built along with the river for flood mitigation as well as the water supply. However, due to resource exclusion caused by government organizational restructuring and the spending of a special budget of 840 billion over eight years, the funding for projects from the Water Resources Agency has shrunk so that the funding for the structural infrastructure might not be as much as before anymore. In conclusion, the capacity to resist floods in Taiwan has been well developed.

9.1.2. Capacity to Absorb and Recover

As the assessment in the previous section, the flood risk management strategies in Taiwan significantly rely on the defence strategy through grey infrastructure such as levees, dams, or off-side retention ponds. The development of the grey infrastructure constricted the river within a small area which resulted in less space for water in the floodplain. The Room for the River approach, which is a relatively natural measure for giving floodplain back to the river, is in discussion with the public; however, the implementation is to a limited extent.

Nevertheless, some non-structural measures were invested in response to the flood threat. The procedure of launching the Emergency Operations Centre for Disaster at every level of government is well established for preparation works such as checking levees and dispatching mobile pumps. The water gauge sensors were installed in the flood-prone area, and they provided information on where to dispatch the mobile pumps. For the community level, there are 542 Self-organized Floods Disaster Prevention Communities which have members clean up the ditch before and after events; in addition, they also help elderly people to evacuate to a shelter. Regarding the early warning system, the warning of extreme weather is sent to citizens via a phone application and text message; however, the interviewees from the government commented that Taiwanese have low awareness and do not even pay attention to the messages.

There are regulations for flood damage compensation on damage to housing and agriculture; nevertheless, there is debate on the difficulty in determining the compensation based; for example, the threshold for getting the compensation is the height of the flood over 50 centimetres. Furthermore, some argued that the compensation is relatively low compared to the damage. Instead of compensation, there is also a system for incentives. The regulation for the Operation of Local Flood Detention Rewards and Compensation was made in 2021 to encourage the citizens to provide their private land for implementing flood detention measures; for instance, after the measure is implemented, the landowner can receive around 330 – 660 euro per hectare every year.

In response to the urban floods, the Runoff Allocation and Outflow Control amendment to Chapter 7-1 of the Water Act was made in 2018. The "Runoff Allocation" is designed to cope with the increased natural rainfall caused by climate change. To utilise the public facilities and space to incorporate the functions such as flood detention and rainwater storage, etc., to increase the land's capacity to store stormwater. The "Outflow Control" ask the developers to take social responsibility by setting up flood mitigation facilities within the development site to share the burden of flooding. The peak flow rate of drainage outlets after development must not exceed that before development. However, the public space mostly belongs to the local government, which has low motivation to implement these kinds of runoff-sharing measures.

9.1.3. Capacity to Adapt and Transform

The capacity to adapt and transform is normally associated with the learning mechanism from the internal and external of the institutions and communities. It also regards the ability of the actors to adapt to new approaches or perspectives. Several active environmental NGOs in Taiwan have dedicated themselves to introducing the latest water management concepts and advocating for policy transformation. Although the Water Resource Agency held the National River NGOs Meetings for over ten years, the conservative government organizations make it difficult to have significant policy changes. Most interviewees agreed that there are some changes in water governance policy, but it is minor and slow. The actual paradigm shift from flood resistance to flood adaptation has still not yet happened.

The cooperation between different institutions brings the chance to exchange knowledge. However, the interviewees commented that despite effective top-down communication within government organisations, communication and collaboration between departments and disciplines are deficient. The interviewee from the government said that cross-discipline cooperation exists in watershed management; for example, they can launch the Water Resources Review Committee and Water Resources Coordination Meeting between Water Resource Agency, Soil and Water Conservation Bureau, and Forestry Bureau, when there is authority confliction between them. In addition, the interviewees explained that formulating Special Statute for specific governance purposes can also provide the environment for breaking down existing boundaries in the different departments in the projects.

Regarding the capacity to adapt and transform from inhabitants, it is argued by the interviewee from academia that the well-established flood control infrastructure hinders water from citizens and hampers their opportunities for learning and building awareness of floods. In addition, the current public participation in the policy decision-making procedure needs to be improved because communication mostly being one-way. In most cases, the citizen was informed when the projects were already ongoing.

9.1.4. Balancing of Flood Resilience Capacities

The assessment of flood resilience reflects that flood risk management in Taiwan is unbalanced. The policy emphasises enhancing the capacity to resist floods through structural measures. As a result, this tendency harm the overall resilience of the system. For example, the construction of grey infrastructure not only takes away the chance for residents to learn from small-scale floods but also confines the floodplain space to absorb water. Besides adjusting the flood control engineering strategy, there are also opportunities to enhance overall resilience in terms of building a more open government to create an environment for learning and trying new methods and concepts.

9.2. Water Governance Assessment

In this chapter, the assessment uses the proposed project of Room for the River in the Tsengwen River Basin. The specific geo-reference location helps to converge discussion in the semi-structured interviews to extract the particular information and knowledge from the interviewees. Attention is paid to how the context influences the main actors in the interaction process. The simplified CIT was applied to organise the interview data in a logical order. With the limitation of contacting all the actors in the decision-making process in time, this study focuses on the perspective of water management policies and related stakeholders' interests. For example, this study does not address the analysis of complex inter-regime in the CIT on how other regimes, such as agriculture, forest, environment, land use planning, etc., influence the water governance regime. It should be noted that the analysis data are mainly from the people who work in the water management field, and the views from other regimes and residents are omitted.

9.2.1. Wider Context

In Taiwan, there is a common belief that the island’s land is small and the population is dense. Several interviewees also expressed the same statement to illustrate the phenomenon of constricting river floodplains for urban development or agricultural purpose. It became the first reaction when discussing implementing a project like Room for the River in Taiwan. However, the interviewee from academic background argued that this is a misconception because the potential has not been adequately investigated. In addition, the interviewee believes that the reaction came from the romanticised image of Western countries being superior due to their better values and ideas, and it needs to break away, although it has been ingrained in Taiwanese culture.

NGOs observed that construction of grey infrastructure for flood defence is considered as a reasonable investment in the society. If landowners feel unsafe on their property, it is common cases for them to seek help from elected representatives to handle the matter. No one feels any guilt about this issue, and it can see that even politicians use this as a political bargaining chip by claiming credit for helping residents obtain funding for flood control infrastructure projects. In addition, most Taiwanese believe that it is the government’s responsibility to keep their property safe, and citizen has no obligation to it. Thus, some interviewees also stated that this is a developmentalism society with the mindset of prioritising economic interests.

9.2.2. Structural Context

At the national basin scale, the Water Resource Agency and its ten regional River Management Offices are responsible for river management. The Regulation of River Management, which is formulated in accordance with Article 78-2 of the Water Act[12], is one of the most critical regulations related to governing river management. The term "river management" in this regulation stipulates the authority of the Water Resource Agency, such as (1) the planning, design, and construction of river governance plans; (2) delimitation and modification of river basin areas; (3) formulation of river environmental management plans; (4) acquisition of land for governance plan implementation purposes; (5) management of structures built for flood control purposes along rivers; (6) designation of areas where soil and stone can be excavated., etc. This regulation determines the river region area by three lines illustrated in table 9.2. Article 82 of the Water Act empowers the Water Resource Agency to requisition the land lying within the Waterway Management Plan Line or the Scope of Land Line or to restrict the use to prevent flooding by submitting the plan to the superior authority for approval and need to announce to the public.

Table 9.2 Definition of Three Water Governance Lines

Name	Definition
Waterway Management Plan Line	Refers to the water's edge or the planned water surface width range line of the river governance plans
Scope of Land Line	Refers to the scope that includes river defence structures or drainage facilities that are planned or already constructed for the waterway, as well as flood control roads, maintenance reserve land, and safety control implementation areas.
River Area Line	Refers to the authority area of the river management agency. It covers vertically from the upstream river boundary point to the estuary and horizontally includes both sides of the river extent of two-year return periods flood-prone areas or within the Waterway Management Plan Line and Scope of Land Line.

Over the past two decades, there has been a noticeable change in policy strategies concerning river management projects. The Flood-prone Area Flood Governance Plan initialled from 2007 to 2013 only served one goal of safeguarding the safety of people's lives and properties. From 2014 to 2019, the Special Statute for the Comprehensive Management of River Basins was formulated to integrate the management of river basins to prevent floods through land planning, flood control and river basin management. The recent special budget for river management is called National Water Environment Improvement Plan (2017-2024), with three objectives – water & development (water supply), water & safety (flood defence), and water & environment (water quality, landscape, and ecology conservation). It can be seen that more values of the river are put into consideration. The project goal is also from the sole objective of ensuring safety to balancing between safety, environment, and development. In addition, the current policy of the national river is called the River Improvement and Adaptation Plan, which starts indicating the importance of blue and green network conservation or runoff allocation. However, most interviewees debated that the change in the projects is minor because the core value of flood control infrastructure for flood defence is still unchallengeable, and doesn't feel too much difference while conducting the project.

Apart from the minor changes in the project's objective, the Water Act amendment in 2018 was considered a breakthrough. Almost all the interviewees mentioned that the amendment of Chapter 7-1 of the Water Act, named the Runoff Allocation and Outflow Control, was a positive change in the water management policy. This new chapter of the Water Act opens the opportunity for cooperation between different government departments. Article 83-4 requests the authority in charge of the runoff allocation plan to invite

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[12] https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0110001

other authorities, such as land administration, urban planning, farmland drainage, or related business, to seek advice from them and integrate the land for allocating the runoff. Nevertheless, interviewees from NGOs and engineering companies observed that it is still challenging to implement in practice; in addition, it is still dealing with the issue regionally but not looking at the whole catchment for solutions.

9.2.3. Specific Context

The historical records revealed that the main waterway of the Tsengwen River changed several times before the flood control infrastructure began in the 1930s during the Japanese colonial period. The meandering nature of the river shaped the unique local culture and the complex land ownership in the area. Interviewees from the government suppose that complex land ownership is a potential obstacle to land acquisition for flood management.

The planned levees construction from the Tsengwen River Water Governance Plan has almost completed in the 2010s with a capacity of 12500 CMS discharge protection standard of a hundred-year return period. Some interviewees considered the pressure coming from urban and industrial development led to the results of further constriction of the Tsengwen River in the recent year. For instance, the Shanshang Industrial Zone, located on the opposite side of the river band of the Danei District and the Tainan Science Park (semi-conductor companies), located downstream of the Tsengwen River, are the development pressure in the surrounding area.

Beginning in the early 1970s, the construction of Tsengwen Reservoir has contributed to flood regulation and water supply; however, it also impacts the river morphology. The natural river dynamic was influenced by the interruption of water and soil supply in the river channel. The unbalance of sediment and water results in the incision of the main channel and deposition on floodplains. The highly artificial effect in the Tsengwen River needs to be aware of while implementing the river management strategies.

In response to the complicated environmental issues in the Tsengwen River basin, the Tsengwen River Environmental Management Plan was completed in 2019, with the ambition of integrating water quality, water quantity, river morphology, ecology, and land use into the basin's long-term master plan. However, although NGOs held a positive attitude towards this plan, it has not been officially approved as a policy goal of the Water Resources Agency. The interviewee from the government explained that they also appreciate the work in this project; nevertheless, the policy targets set in the project are too challenging to achieve in the proposed time to become an official announcement.

9.2.4. Motivations of Actors

The internal primary motivation of the Water Resource Agency and the Sixth River Management Office is to warrant the residents' safety from floods. The Water Act and related regulation assigns responsibilities of river management to them. They held a solid responsibility to ensure the river water won’t flow over the top of the levee under the designed protection standard. If the protection failure happens and causes damage, they might face public criticism and even pressure for state compensation. The external motivation is mainly from the media and public while the floods occur. The government interviewees complained that they are now exhausted from rushing to deal with the widespread media reports of flooding; however, from a water engineering perspective, short periods of localised flooding lasting only a few hours are fairly normal. Industrial development put extra pressure on urban development, and it also became another indirect external motivation for the government to safeguard these valuable properties from being damaged.

The motivation from the engineers mainly came from the obligation of executing the contract from the government. Some of them said that the flooding issue became their first priority partially because the Water Resource Agency places great importance on it, while others believe that we need to find a way to balance the different aspects, such as flooding, ecology, water supply, etc., at the same time. Regarding the interviewees from academia and NGOs, the motivation is more personal and diverse. Some of them start with caring about the surrounding riverine area, others care about the ecosystem should maintain its natural existence and value in its own form, the others pay attention to problems caused by the devastation from grey infrastructure cemented over rivers and want to challenge the mindset of believing it is an unnegotiable or unavoidable choice.

9.2.5. Cognition of Actors

The common cognition among Taiwanese is that the rapid development and the dense population on this small island bring pressure to limit the river area. However, some interviewees argue this is a misconception because our spatial planning and land use management were unappreciated in the past decades. There was no zoning concept in the Taiwanese land administration system in the rural area before the formulation of the Spatial Planning Act in 2016. In the Spatial Planning Act, the river corridor is demarcated as the environmental conservation zones with the principle of protected areas, and the usage of land may be prohibited or restricted. Although some consider that the river corridor has not been demarcated properly, it is still a breakthrough in the land administration system.

In the hydraulic engineering system, the conventional perception is to drain away the runoff into the sea as soon as possible. Natural meandering rivers were strengthened and channelised to make the water could drain out of the urban area in a short time. However, this has been questioned that it just transfers the risk downstream. In addition, there is an unchallengeable belief that the urban area cannot be flooded. “No flooding” became a slogan of the construction of flood control infrastructure; thus, it became a burden to the governance to keep strengthening the capacity of flood resistance. People from academic and NGO initiatives that the public need to build flood perceptions and learn how to adapt, tolerate, live with, and recover from it.

Another cognition held by most people with engineering backgrounds is that the current levee system can protect safety under certain protection standards or even withstand the challenge of climate change. In addition, they observed that the pattern of rainfall changed in the past decades, and there were fewer typhoons landed in Taiwan. The type of floods caused by river overflow seemed to be secured by some interviewees, and nowadays, floods come from extreme rainfall in a short time in the urban area. In contrast, some said that this safety is built on maintenance without margin for mistake; furthermore, the unforeseen uncertainty from climate change, or if we look back the history, severe floods already happened before and might be more extreme in the future. If we look at lifetime-long or longer periods, there is always a chance of catastrophic disasters.

9.2.6. Resources of Actors

In the water management system, the government holds the majority of resources on finances and power. Most of the funding of consultant engineering companies is from projects commissioned by the governments. The companies have an obligation to fulfil the demand of the contract, and the government holds the power to decide on the members of the examining committee to determine whether a company meets the contract requirements for payment. Some interviewees with engineering company experience stated that there is no mutual communication between the company and the government. They felt that the companies are seen as the extension of the will of the government to conduct projects. However, some engineers expressed different experiences in the interviews. Since the companies held the resource of skilled people and knowledge, it remained some space for negotiating with the government and saying no. The others said communication with the government is a gradual process, especially for some new concepts that the government is still conservative with. In the cases that the government really want to do something or feels external pressure that this must be done, there will be room for further dialogue. So, finding a way to create an atmosphere in public to make the government pay attention can be a strategy. In the system, NGOs represent a certain degree of public opinion and play a role in lobbying with the government. Their resources come from their influence on legislators and the atmosphere they shape for public advocacy. The power interaction among the different parties is demonstrated in figure 9.1.

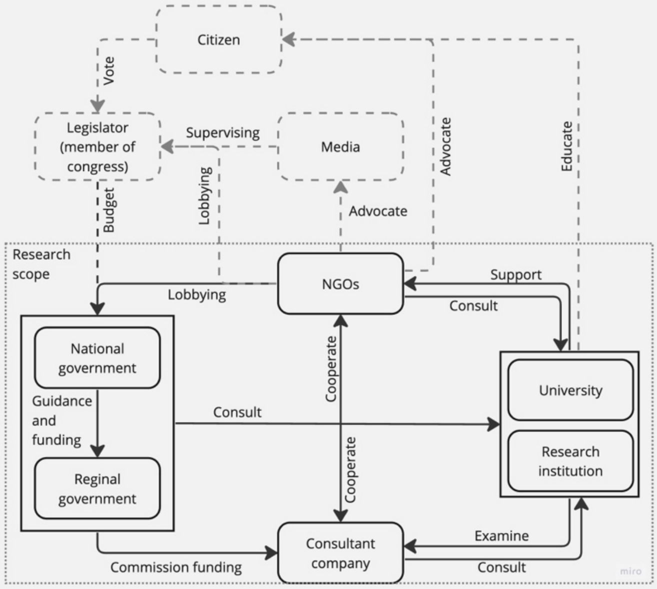

Figure 9.1 Resource Interaction Between Actors

9.3. Recommendation on Implementing RftR Approaches from the Interviewees

In the interviews, all the interviewees consider that the proposed RftR intervention with the lowing of the floodplain is easier to implement because it is in the authority area of the Water Resource Agency and the government mostly owns the land. However, some doubt that if this area is natural to be deposited, then the intervention might not maintain for a long time. In addition, one of the interviewees argued that although in the Dutch context, it is an RftR approach, it is not actually returning the land to the river. The interview debated that lowering floodplains does not necessarily create more room horizontally for the river.

Regarding the intervention of setback levees, all the interviewees hold a positive attitude toward it; nevertheless, this approach is challenging the current water governance regimes, so it is difficult to implement. Most of the interviewees agreed that funding, skilled people, and technique are not the problems. The obstacle came from the difficulty of land acquisition and a lack of social consensus. As mentioned in section 9.2.2, there is a legal tool for the Water Resource Agency to requisition the land lying while announcing the within the Waterway Management Plan Line or the Scope of Land Line. Some thought that these two lines were the result of the negotiation with the stakeholders, so it makes it difficult to make a change again. In addition, the change of these two requires the legal procedure of re-launch the Water Governance Plan to conduct the hydraulic analysis again. However, although it is difficult, there are existing tools for implementing the intervention.

The primary obstacle is the lack of society's consensus. Even if there is a strong legal reason for land acquisition, the government might still face strong protests. The citizen put their own profit in the first place, so if there is not too much benefit for them to gain from it, there is no motivation for them to sacrifice or contribute private land for public or environmental goods. Some interviewees suggested that the value of ecosystem service needs to be quantified for and rational judgment of whether the intervention is worthy so that the decision won't only be made for serving one purpose (e.g. flood regulation) or only look at the economic benefit. In addition, some interviewees were also reminded that the perspective of river morphology should also be involved in leading the designs is follow the river's natural characteristics and find the balance of water and soil.

10. DISCUSSION, CONCLUSION, AND RECOMMENDATION

10.1. Discussion

10.1.1. The Wickedness of the Study

Implementing the Room for the River approach in the Tsengwen River is a wicked problem. Most of the literature on wicked problems leans toward Rittel & Webber's (1973) ten characteristics of wicked problems (Alford & Head, 2017). Overall a wicked problem has no ultimate solution, and the solutions are not true or false but good or bad (Rittel & Webber, 1973). Alford (2017) framed the wicked problem into a two-dimension matrix, focusing on the wicked situations of the problem itself and the actors involved. A problem, which has high complexity and high conflict in values and interests among actors, is seen as a wicked problem. Wickedness can decrease, by understanding the problem better and/or by creating more consensus among stakeholders about potential solutions.

With regard to flood risk management in the Tsengwen River basin, tackling fluvial floods caused by typhoons in this complex basin, which is highly influenced by humans, is a complex problem. On top of that, different actors in the system held various interests and values, increasing the difficulty of decision-making in the area. This study attempts to address two aspects simultaneously, aiming to understand the wicked situation better and make it less wicked. OpenLISEM was used to analyse the complexity of the flooding problem in the basin. The role of the dam operation was identified, and several interventions were simulated to evaluate their effectiveness. The flood resilience framework was applied to assess the current flood risk management in the water governance system and provides information on how to make the system more resilient. In addition, the water governance regime and the various interests, motivations, and resources held by stakeholders were assessed by applying the Contextual Interaction Theory (de Boer, 2012). This assessment clarifies the conflict of interest among actors and the restriction of implementing the RftR approach under the current water governance regime.

10.1.2. The Notion of Flood Resilience in Flood Risk Management in Tsengwen River Basin

Flood resilience has been proposed as the ideal and desired outcome of flood risk management in the scientific literature (Driessen et al., 2018). The typical strategy for managing flood risk is to use resistance-based strategies, which try to limit flood hazards with infrastructure and control behaviour with laws and regulations; however, it does not deal with uncertainty well (Morrison et al., 2018). Resisting floods through levees, dams, and channelization ignores inherent uncertainties emerging from human-nature couplings and fails to address the extreme events that are predicted to rise with climate change (Liao, 2012). Wardekker (2010) stated that the resilience-based approach should be capable of limiting consequences even if their magnitude and direction are uncertain or unknown. For this reason, emerging literature calls for a paradigm shift in flood risk management from resistance to resilience (Fekete et al., 2020; Hartmann & Driessen, 2017). This study assessed flood resilience in flood risk management through interviews with the key actors in the system. Research in flood risk management has the ability to offer fundamental insights into the discussion of how to increase societal resilience to floods (Driessen et al., 2016).

The flood resilience framework developed by Hegger (2016) was applied in this study to assess flood risk management. The assessment results indicated that the current flood risk management in Tsengwen River Basin mainly emphasises flood protection. The flood control infrastructure has been well constructed and provides protection standards with 100 years return period, and its related maintenance and monitoring works are also implemented. The accomplishment of conventional infrastructure has resulted in fewer floods in the past decade. In contrast, the assessment of the capacity to absorb and recover, and the capacity to transform and adapt show multiple negative indicators. Although some measures were taken, overall, these two aspects haven't been well addressed. Hegger (2016) stated that the desirable flood resilience should seek the balance among these three capacities because there are potential trade-offs in between. It was argued that the resistance infrastructure erodes resilience because it hinders the chance to learn from frequent small floods (Liao, 2012), and leads to more intractable problems in the long term future (Walker & Salt, 2012).

In addition, the applied flood resilience framework in this study is specifically designed for assessing resilience in flood risk management strategies; consequently, the role of residents is marginalised. Since flood risk management ends up influencing society, communities play a crucial role in whether the system's resilience can be enhanced. It is worth exploring how the communities react to floods because the learning from flood mechanisms might differ in the different environments (Kuang & Liao, 2020). It should be noted that the absence of communities is the limitation of this research. In summary, the flood risk management in the Tsengwen River Basin is unbalanced among these three capacities. The flood resilience in the system can be enhanced by implementing the measures, such as loosening the constriction of the floodplain and finding a way to introduce learning mechanisms to floods for citizens and cross-discipline departments in the government.

10.1.3. Water Governance Regime in the Tsengwen River Basin

The RftR approach in the Tsengwen River Basin brings the discussion with interviewees on the georeferenced site and takes their focus together. The environmental, historical, and cultural background, as well as the law, regulation, and influence of previous decisions in the area, shape the current circumstance in the Tsengwen River basin. The actors involved in the water governance decision-making process have a complex interaction with each other driver by their motivation, resource, and cognition.

The Water Act and the River Management Regulation empower the Water Resource Agency (WRA) to have the right to manage all the activities in the river region. However, the legal water governance line listed in table 9.1 restricts WRA's imagination of river basin management as a linear but not spatial planning. On the one hand, the area out of these governance lines is beyond the WRA's authority. On the other hand, the lines were drawn through complicated legal procedure, so changing the lines are difficult. The cooperation between government departments could break the restriction; however, some interviewees commented that there is no decent cooperation among cross-discipline departments in the government system. Some interviewees argued that the statutory restriction is not unconquerable; it's just because the government lacks the motivation to do it. In addition, the natural flood-prone environment is also the reason that the system is dedicated to developing flood control infrastructure to regulate and defend the flood to prevent public property from being damaged.

Regarding the interaction among the actors, the government held the primary resource on finances and power, which means their cognition and willingness are keys to influencing the projects that shape the environment. Although other actors can also affect the decision-making, it is relatively minor. The motivations for the government's actions are their responsibility internally and the pressure of society externally. To warrant the citizen's safety is the leading mission in their works, and the conventional infrastructure is the guaranteed solution in their cognition to prevent public property from being damaged by floods. The motivation for engineers is the obligation to fulfil the contract with the government. About the interviewees from the academia or NGOs, the motivations come from self-interest in conserving the natural environment or the quality of the nearby living riverine area. The RftR approach could potentially satisfy their expectation of natural or muti-functional riverine areas. Some interviewees believe that the ecosystem service should be used as a tool to balance the values provided by rivers.

This study conducted ten interviews with interviewees who work in universities, NGOs, engineering companies, and governments. However, the ten interviewees have not covered all disciplines and roles in the water governance regime, which brings uncertainty to the result. Firstly, the local organisation, governance, and citizens are not involved in the study. Second, the multiple inter-regimes, which include departments from different disciplines in the government system, are not in this study's scope. These two limitations constrain the viewpoint of how the result reflects the current system.

10.1.4. The Flood Hazards Simulation

The flood characteristic and the flood hazards for proposed interventions in the Tsengwen River basin were analysed by OpenLISEM. The result provides numerical information on how the effectiveness of the interventions. In the flood simulation in this study, some assumptions were made, and some uncertainties were introduced. In addition, the model has its limitation in representing the real-world characteristic.

In this study, although the OpenLISEM can simulate evaporation, it is not executed in the simulation. An assumption was made that evaporation has a minor influence on the result and was not included for two reasons. First, there is only one available station data of evaporation in the modelling domain. Using one station data to represent the whole catchment only introduces uncertainty in the model. Second, in the OpenLISEM setting, the evaporation process stops when heavy precipitation occurs. During the typhoon, the amount of water from the evaporation process could be ignored. The other assumption is related to interception and surface storage. The amount of water captured by vegetation and surface storage is based on the assumption of plant cover and random roughness value. However, these two parameters can have little impact on the result, especially in the typhoon event.

The uncertainties introduced in each input data, such as rainfall, DTM, land cover, and soil properties, should be aware. The inverse distance interpolation method was used to generate spatial distribution from four ground gauge stations. This method only considers the horizontal geographic coordinator of the stations. Nevertheless, the precipitation tends to increase with elevation, and this topography effect is neglected (Goovaerts, 2000). DTM is an important data source in OpenLISEM because it generates topographic attributes, including the simulation domain, slope, river network, etc. The DTM was resampled to 100 resolutions, and the coarse resolution has an impact on the flow pathway and water depth predictions (Savage et al., 2016). Regarding the land cover, it was converted from the land use map, so it might not accurately represent the land cover types. In addition, it used the majority land cover area to represent the grid cell; therefore, the diverse land cover in a grid cell was united type, which caused uncertainty to the model simulation.

There is a limitation in creating levees and channels in the OpenLISEM. As mentioned in section 5.2.3, the levees can only be built through superimposed on the DTM, so it cannot create levees with smooth elevation as in reality. Regarding the channel, OpenLISEM is limited to directly inserting cross-section data in the model. The channels were created by assigning the width and depth by regression formula. The height of the levees was calculated by the average differences between DTM and cross-section data for each levee segment. Since the simulated discharge is within the designed capacity, the decision was made to enhance the elevation of the levee to avoid the river water over the top of the levees. About the channel, the rectangle channels cannot perfectly represent the river cross-section, so even if the simulated discharge is quite accurate, the accuracy of the water level might be influenced because of the difference of cross-section in reality and in the model.

The intervention simulation results indicated that the RftR approach has a maximum impact of reducing water level by only around 7 cm. On the other hand, the optimised dam operation can decrease the high-water level by 1.5 meters. Concerning urban flood hazards, the simulation result indicated that the floods in the urban area come from precipitation and runoff, but not the water from the river. In addition, since the urban drainage channel and the sewer system are not about to build into the model because of a lack of data and model limitation, the inundated area might be over or under estimated. However, the event happened in 2009, it is difficult to find an inundated map to validate the simulated flood extent via remote sensing. Regarding the effectiveness of the intervention, building detention ponds near the built-up area does not noticeably influence the inundated area.

With regard to the RftR interventions, this study only simulated the hydrological process and evaluated the effectiveness of focusing water domain. In practice, the designs should aim for as little maintenance in the future as possible, which means the natural hydraulic, morphology (involved erosion and sedimentation), and biotic processes should be put into consideration to find the dynamic stability in the floodplain and riverbed (Klijn et al., 2013). The RftR frequently have a significant influence on water flow and sediment transport, which sometimes result in excessive dredging maintenance, so counterbalancing the morphodynamic impacts in the river is essential (van Vuren et al., 2015). Lane's balance (Lane, 1955) states that the equilibrium in a natural stream is related to the dynamic balance between the water (water discharge and slope) and sediment (sediment discharge and size). It should be noted that the equilibrium of these four variables is crucial when implementing the RftR designs into practice.

10.1.5. The Feasibility of Implementing the RftR Approach in the Tsengwen River

From the perspective of hydraulic effectiveness, the RftR approach seems not significantly effective as a flood risk mitigation measure in the Tsengwen River. Nevertheless, the assessment of the Q-team (Quality Team Room for the River), established by the Minister of Transport, Public Works and Water Management, revealed that the hydraulic effect in several RftR projects were also under ten centimetres (Klijn et al., 2013). On the one hand, the implementation in this study is only at one location. However, in the Netherlands, the RftR programme is a series of projects along with the river. The integrated basin plan of the RftR approach might have a synergy effect on reducing downstream flood hazards. On the other hand, the potential added values from the RftR approach should be considered. For example, appropriate designs could encourage ecological stability and dynamic processes in selected river-floodplain areas (Juarez Lucas & Kibler, 2016). The concept of the RftR is an integrated approach that combines flood safety with other values such as landscape, environment, and culture (Zevenbergen et al., 2015); in other words, it is to find the balance of hydraulic effectiveness, ecological robustness, cultural meaning, and aesthetics (Alphen, 2020; Klijn et al., 2013). The flood modelling can only provide information on hydraulic effectiveness. Exploring the contribution of other values requires detailed designs of the study area and other different assessment tools, which are out of this study's scope.

The challenge of transferring the Dutch RftR approach to other jurisdictions is not just about implementing technology, it requires a fundamental shift in the governance and culture (Bogdan et al., 2022). The RftR brings the transition of replacing flood risk management from an engineering aspect to incorporating various disciplines (Rijke et al., 2012), and it was recognised as the lead in multi-level governance of guiding how to reform the institutional arrangement (Zevenbergen, Rijke, et al., 2013). Moreover, to achieve its flood risk, environmental, and broader societal objectives, RftR's innovative initiatives need social and network learning (van Herk et al., 2015). As the RftR approach created new linkages between water and land, this policy brought a new challenge for communication with the inhabitants impacted by river interventions (Roth et al., 2021). Governance in RftR emphasizes early community involvement as well as cooperation between various government levels and departments (Rijke et al., 2012). From the flood resilience aspect, the cooperation of different disciplines and social learning can support the future programme; the capacity to adapt and transform can be enhanced in terms of the flood resilience framework. This study would argue that implementing the RftR approach is not only focusing on the physical perspective but bringing the transition in flood risk management and the learning mechanism of social learning could be the starting point of the paradigm shift from flood resistance to flood resilience.

The obstacle and the potential of implementing the RftR approach in the Tsengwen River under the current water governance regime were explored based on interview feedback from the experimental actors. The obstacles mainly come from society not yet having a consensus on it, and reconstructing (levee setback) involves complex legal procedures and land acquisition. In addition, the lack of experience in cross-discipline cooperation might be an issue. However, there is still the potential to implement the RtfR because already enough policy tools exist. Some interviewees argued that the Water Resource Agency is not motivated enough or ready to incorporate other specialise into river management. In addition, communication with the stakeholder should happen in the early stage of planning, but not a one-way announcement in the late stage of the projects.

10.2. Conclusion

Flooding can be perceived as a wicked problem. The causes and consequences of floods are embedded in complex sociopolitical contexts with numerous stakeholders of various interests and views that impact how problems are formed or perceived, influencing which policies are selected and later executed (Bogdan et al., 2022). This study contributes to making the problem less wicked by improving the flood characteristic and water governance regime of the Tsengwen River basin. The contributions are based on technical analyses of simulating flood hazards by hydrological model and social analysis of flood resilience and water governance assessment by applying theoretical frameworks.

First, this study demonstrates how the flood resilience framework (Hegger et al., 2016) and the Contextual Interaction Theory (de Boer, 2012) can be applied to assess flood risk management and water governance in the Tsengwen River basin. On the one hand, the assessment provides a lens of flood resilience to evaluate the Tsengwen River basin's flood risk management strategies. The evaluation indicates that the current flood risk management strategies are biased towards the capacity to resist floods. The tendency might erode the flood resilience in the system because there are potential trade-offs among the three capacities. On the other hand, the potential of implementing the RftR in the current water governance context and how the interaction among actors in between is evaluated. The assessment reveals that the primary obstacle to implementing the RftR approach is stakeholders' various interests and cognition, leading to the lack of societal consensus. However, there is a potential to implement the RftR approach in the Tsengwen River because the policy tools, skilled people, techniques, and finance already exist. Furthermore, although this research does not integrate the resilience theory with water governance as one framework, the assessments on both sides explicate how these two could complement each other to provide an intact view of complex sociopolitical contexts in flood risk management.

Second, the assessment of the water governance regime reveals how the cultural context, regulations, and previous projects shaped the study area, and how the government interacts with society. It is no doubt that the Water Resource Agency held the primary resource (power and finance) to a project; in contrast, other actors have a relatively minor influence on how the decision is made. The cognitions and motivation toward the flood problems, which vary from stakeholders' backgrounds, are the driver of actors to influence flood risk management. By offering insights into resource interactions between stakeholders and the understanding of their cognition and motivation, this research contributes to a better knowledge of the functions of framing in flood risk management and policy transfer.

Third, the flood characteristic during the Typhoon Morakot event in the Tsengwen River basin is simulated, and the effectiveness of the proposed interventions is evaluated. The flood hazards surrounding Danei District in different scenarios are simulated with comparisons of their extent and height. The major contribution of flood modelling is the understanding of the hydraulic effect of different interventions and how it relates to flood characteristics and geographic conditions. The calibration on the discharge demonstrates excellent performance, which can be the input data for further simulation with higher resolution, and the flood hazard information could contribute to further flood risk analysis in other studies.

In conclusion, this study explores the feasibility of transferring the Dutch RftR approach to the water governance regime in Taiwan. A deeper understanding of the feasibility of implementing the RftR approach in the Tsengwen River basin might assist the actors in water governance in anticipating the obstacles and conflicts when implementing the RftR in specific political and geographical situations.

10.3. Recommendations

This study provides some recommendations for further research to improve the reliability and usability of the result, and to obtain more holistic insights on improving flood resilience in the Tsengwen River basin under the current water governance regime.

Firstly, developing a framework that integrates flood resilience in water governance would be valuable. This study shows the potential value of integrating the concept of resilience in water governance assessment. This combination could provide a comprehensive understanding of how the water governance context with the interaction of stakeholders could shape the system to become more resilient to floods. However, in this study, the assessments are based on two separate frameworks, so the results are independent. Several research has also identified the challenge of integrating resilience in water governance. It would provide a more meaningful scholarly contribution to developing an integrated framework with flood resilience in water governance than this study has achieved.

Secondly, more stakeholders could be involved in future research to provide a more comprehensive overview of the water governance regime and how flood resilience could be improved. The conducted semi-structured interviews only involve the actors in the water governance regime at national and regional levels. The limitations of reaching all types of stakeholders confine the viewpoints of this study. The influence of external governance regimes, local governments, and residents is omitted in this study. Since the RftR approach implicates cross-discipline cooperation and the early citizens' involvement, the perspective of the absent actors in the study is suggested to be considered in the future.

Thirdly, this study recommended that further research could conduct flood simulation in a finer resolution to provide more accurate information on flood hazards. The simulated discharge in this study can be input data in a smaller modelling domain with a higher resolution sub-catchment. The accuracy of the cross-section and the levees' elevation can be improved, which can help decrease the modelling result's uncertainty. In addition, the flood extent and height could also be more precise due to the finer resolution DTM represents better on the real-world terrain.

Finally, the fluvial morphology of the catchment needs to be investigated. The natural equilibrium of the water flow and sediment discharge is recommended to analyse in future research. The natural process which shapes the riverbed and floodplain should be considered in the practical RftR designs to find the dynamic stability of the river. Working with nature could avoid excessive dredging maintenance and make the intervention more sustainable.

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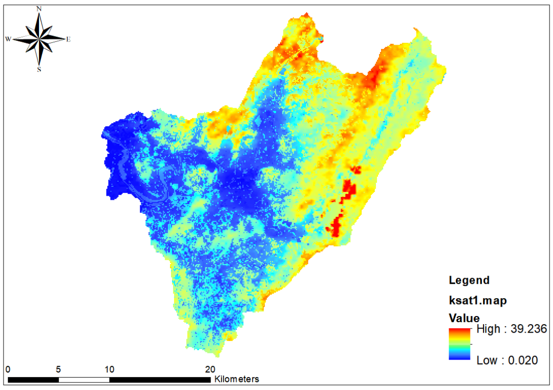
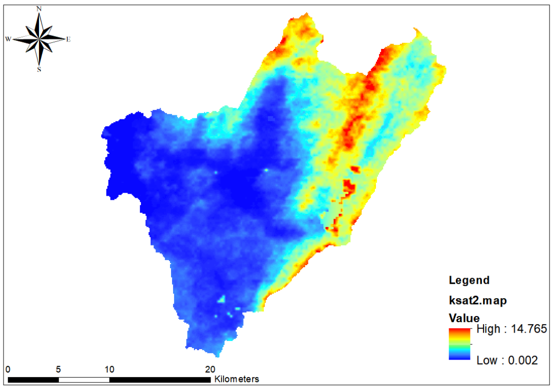
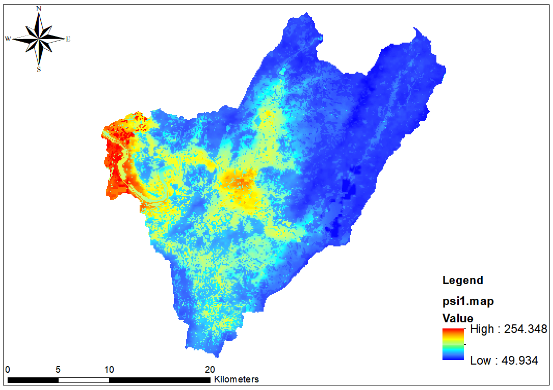
ANNEX 1. INPUT MAPS FOR OPENLISEM SIMULATION



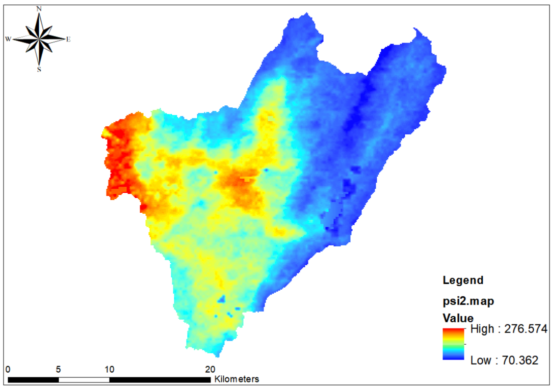
Saturated Conductivity (Ksat) Layer 1



Saturated Conductivity (Ksat) Layer 2



Average Suction at Wetting Front (Psi) Layer 1



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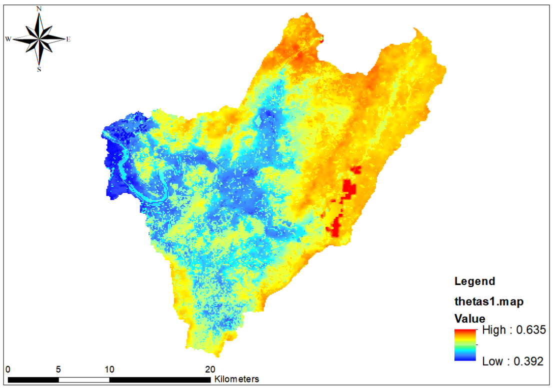
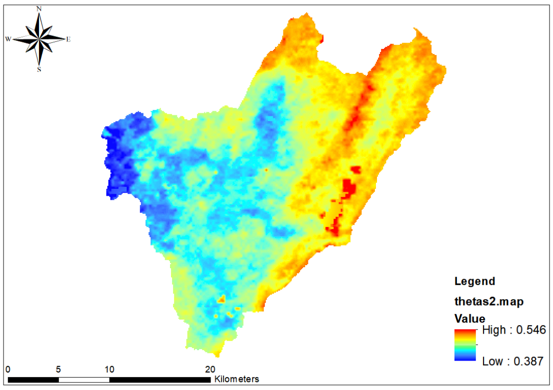


Porosity (Thetas) Layer 1



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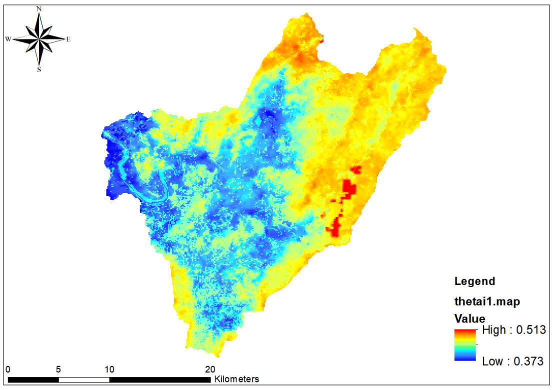
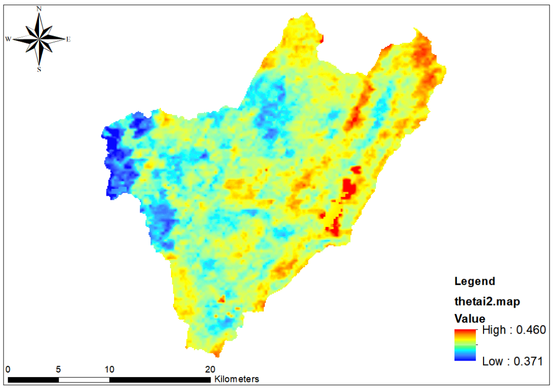


Initial Moisture Content (Thetai) Layer 1



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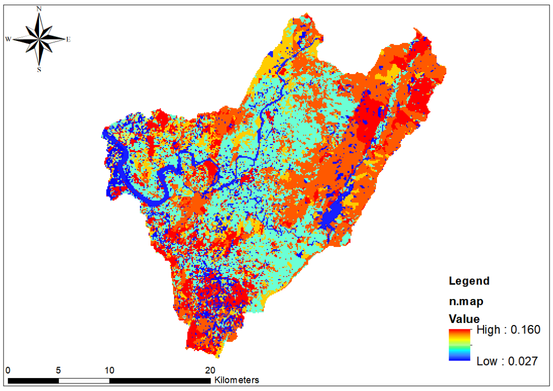

Manning’s Surface Roughness Coefficient (n)

ANNEX 2. COMPARISON TABLE OF LAND USE COVERT TO LAND COVER

Original land use	Convert land cover	Original land use	Convert land cover
Paddy field	paddy fields	Mixed-use residential	built-up
Dryland field	upland fields	Manufacturing industry	built-up
Orchard	orchard	Warehousing	built-up
Aquaculture	aquaculture	Religious	built-up
Animal husbandry	animal husbandry	Funeral facilities	built-up
Coniferous forest	coniferous forest	Other built-up land	built-up
Broadleaf forest	evergreen broad-leaf forest	Government agency	built-up
Bamboo forest	bamboo	School	built-up
Mixed forest	forest mix	Healthcare	built-up
Shrubland	shrub	Social welfare facilities	built-up
Other forest land use	bare land	Public utilities	built-up
Bare land	bare land	Environmental facilities	built-up
Vacant land	bare land	Cultural facilities	built-up
Agricultural-related facilities	built-up	Recreational facilities	built-up
Airport	built-up	Mining and related facilities	built-up
Conventional railway and related facilities	built-up	Earth and stone-related facilities	built-up
High-speed railway and related facilities	built-up	Salt industry and related facilities	built-up
Subway and related facilities	built-up	Construction waste and surplus soil disposal site	built-up
National highway	built-up	River	Waterbody
Provincial highway	built-up	Channel	Waterbody
Expressway	built-up	Reservoir	Waterbody
General road	built-up	Lake	Waterbody
Road-related facilities	built-up	Water storage pond	Waterbody
Port	built-up	Waterway sandbar beach	Waterbody
Embankment	built-up	Sea surface	Waterbody
Hydraulic structures	built-up	Park and green space plaza	grassland
Flood control road	built-up	Grassland	grassland
Commercial	built-up	Wetland	swamp
Residential only	built-up	-	-

ANNEX 3. LAND USE / LAND COVER RELATED PARAMETERS

LU Class	#	RR (cm)	Manning's n (-)	Plant Heigh (m)	Plant Cover (-)	Bulk Density factor	Smax Eq.nr	Root Cohesion kPa
paddy-fields	1	1	0.1	0.5	0.5	1.2	1	4
upland-fields	2	1	0.035	0.5	0.2	1	1	4
orchard	3	1.5	0.08	2	0.3	1	1	4
aquaculture	4	0.5	0.0375	0.1	0	1	0	-1
animal-husbandry	5	1	0.032	0.3	0.3	1	1	4
coniferous-forest	6	2	0.12	30	0.8	0.9	6	6
evergreen-forest	7	2	0.12	20	0.9	0.9	6	6
bamboo	8	1	0.15	5	0.6	0.9	6	4
forest-mix	9	2	0.14	20	0.7	0.9	6	6
shrub	10	1	0.115	1	0.9	1	7	4
bare-land	11	1	0.0265	0	0	1	0	-1
built-up	12	0.5	0.16	15	0.1	1.1	0	-1
Waterbody	13	0.5	0.0375	0	0	1	0	-1
grassland	14	1	0.0375	0.3	0.8	0.95	8	4
swamp	15	1	0.0675	0.3	0.5	1	0	-1